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RESISTANCE OF TRANSOM-STERN CRAFT IN THE PRE-PLANING REGIME

John A. Mercier, et al

Stevens Institute of Technology

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DAVIDSON LABORATORY

Stevens Institute of Technology
Castle Point Station
Hoboken, New Jersey 07030

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RESISTANCE OF TRANSOM-STERN CRAFT IN THE PRE-PLANING REGIME

by

John A. Mercier and Daniel Savitsky

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The statistically-based correlation equation is a function of slenderness ratio, beam loading, entrance angle, ratio of transom area to maximum section area and volume Froude number. This equation can be used to estimate the low Froude number resistance of planing hull forms in the early stages of design.

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KEYWORDS

Hydrodynamics

Ship Resistance

Planing Craft

Hump Drag

TABLE OF CONTENTS

NOMENCLATURE

A_i	i^{th} coefficient of resistance-estimating Equation (5) or (6)
A_T	transverse section area at transom, ft^2
A_X	maximum transverse section area, ft^2
B	beam, in general, ft
B_T	waterline beam at transom, ft
B_X	maximum waterline beam, ft
C_A	correlation (roughness, etc.) allowance on specific resistance
C_B	block coefficient
C_F	specific frictional resistance (e.g., Schoenherr formulation)
C_M	midship section coefficient
C_P	longitudinal prismatic coefficient
C_{TL}	Telfer's resistance coefficient, $R_T L/\Delta V^2$
C_V	speed coefficient (used for planing hull analyses, especially), $V/\sqrt{gB}$
C_{wp}	waterplane coefficient
C_Δ	static beam-loading coefficient, $\Delta/wB_X^3 = \nabla/B_X^3$
F_{n_L}	length Froude Number, $V/\sqrt{gL}$
$F_{n\nabla}$	volume Froude Number, $V/\sqrt{g\nabla^{1/3}}$
g	acceleration of gravity, 32.2 ft/sec^2
i_e	half-angle of entrance of waterline at bow, deg
L	length, in general
L_k	wetted length of keel (see Fig. 1), ft
L_{pp}	length between perpendiculars (at design waterline endings), ft

L_{WL}	length of waterline, ft
$\overline{LCB}$	distance of center-of-buoyancy from ⊗, ft, positive aft
$\overline{LCG}$	distance of center of gravity from ⊗, ft, positive aft
R	resistance, in general, lb
R_T	total resistance for craft, lb
R_R	residuary resistance, lb
S	wetted surface, ft^2
T	draft (maximum), ft
U	$\sqrt{2i_e}$ (parameter in resistance-estimating Equation (6))
V	speed, ft/sec
W	A_T/A_X (parameter in resistance-estimating Equation (6))
w	specific weight of water, lb/ft^3
X	$\nabla^{1/3}/L_{WL}$ (parameter in resistance-estimating Equation (6))
Z	C_Δ (parameter in resistance-estimating Equation (6))
α	coefficient in equation for estimating effect of variation of LCG on resistance (Eq.B-1, Appendix B)
β	deadrise angle, deg
β_i	coefficient in equation for estimating effect of variation of LCG on resistance (Eqs.B-1,B-2, Appendix B)
γ_i	Coefficient in equation for estimating effect of variation of LCG on resistance (Eqs.B-1,B-3, Appendix B)
Δ	craft displacement, lbs
δ	LCG position parameter, see Appendix B
∇	craft displaced volume, ft^3
λ	mean wetted length-beam ratio (see Fig. 1)
λ_{c_1}	chine wetted length-beam ratio (see Fig. 1)
λ_{c_2}	side wetted-length-beam ratio, where flow which separated from chine may reattach to side of prismatic hull (see Fig. 1)
τ	trim angle of planing area, deg

INTRODUCTION

Marine craft designed as planing hulls are intended to be small, high-speed boats operating at volume Froude numbers greater than approximately 2.0. When properly configured, planing craft are characterized by a transom stern and hard chines to provide for early flow separation from the transom and chines; by straight buttock lines aft to develop positive dynamic pressures; and by a combination of loading and center-of-gravity location to assure some positive hull trim and complete emergence of the bow when "planing." For such operating conditions, prediction procedures, as given by Savitsky[1] and Hadler[2] for prismatic hull forms, provide guidance in making smooth-water performance estimates. In fact, these procedures can be used to identify planing inception to occur at that speed at which the computed wetted keel length is less than the LWL of the hull so that the bow is lifted clear of the water.

Every planing hull must, of course, pass through the non-planing speed range when the bow is immersed. Further, although an original design may have been a successful planing hull, in time its payload may increase so that it is no longer capable of attaining planing speeds. Also, in certain military applications the constraints imposed upon maximum draft, beam or length of the craft, generally result in a boat which is too small for the specified payload so that the bow is immersed throughout the speed range. For these "non-planing" conditions, there is no analytical procedure for estimating the smooth-water performance nor for providing design guidance in selecting optimum hull dimensions and proportions. It is necessary to resort to model tests, or to planing hull series data, if applicable to the contemplated design.

The purpose of the present report is to present an analytical procedure capable of predicting the hydrodynamic resistance of transom stern hulls in the non-planing range -- specifically for volume Froude numbers equal to or less than approximately 2.0. For higher speeds, it is expected that the planing formulations of Reference 1 will be applicable.

The non-planing predictive technique is established by a regression analysis of the smooth-water resistance data of seven transom-stern hull series which included 118 separate hull forms. The analysis derives a statistically based correlation equation which is a function of slenderness ratio, beam loading, waterline entrance angle, and ratio of transom area to maximum section area. This equation can be used to estimate the resistance of other forms in the early stages of design. Separate equations are developed for each volume Froude number.

A complete description of the characteristics of the 118 models of the seven transom-stern hull series, including body plans, bow and stern profiles, design waterline endings, and the resistance characteristics, are contained herein. A brief analysis of the effect of LCG on resistance is also presented. Illustrative examples are included demonstrating the application of the predictive technique to several ad hoc hull forms. The effect of changes in form parameters on resistance is demonstrated and, finally, the statistical accuracy of the predictive procedure is discussed.

This study was sponsored by the Naval Ship Systems Command and administered by the Office of Naval Research under Contract N00014-67-A-0202-0014.

HYDRODYNAMIC PHENOMENA RELATED TO PLANING HULLS IN SMOOTH WATER

In order to provide a proper perspective for the results of the present study, a description is given of the hydrodynamic phenomena associated with transom-stern hulls when running in smooth water over a wide speed range.

a) At zero and low speed, planing boats are displacement hulls, obtaining their entire lift by buoyant forces.

b) As speed increases, to speed coefficient (based on transom beam) $C_V = V/\sqrt{gB_T} \cong 0.50$, there appears the first visual evidence of the influence of dynamic effects upon the flow patterns. Complete ventilation of the transom occurs and appears to be independent of deadrise, trim, or hull length for typical values of these parameters. Also, as shown in Reference 1, there is a loss in resultant hydrodynamic lift wher compared with the purely static lift corresponding to the draft and trim of the craft. The bow is, of course, immersed at this speed and adds to the total hydrodynamic drag.

c) At speed coefficients between 0.5 and 1.5, the dynamic effects produce a positive contribution to lift although, in most cases, not sufficient to result in a significant rise of the center of gravity or emergence of the bow. Generally, the flow has only slightly separated from the forward length of the chine so that there is significant side wetting. In this speed range, the craft is essentially a high-speed displacement hull. It is within this speed range, where there is bow immersion and large side wetting, that a suitable analytical procedure for resistance estimates does not exist. This is essentially the speed area covered by the present study.

d) At speed coefficients larger than approximately 1.5, a well-designed planing boat should develop sufficiently large dynamic lift forces to result in a significant rise of the center of gravity, some positive trim, emergence of the bow, and separation of the flow from the hard chines. The hydrodynamic resistance is due to the horizontal components of the bottom pressure force and the friction component of flow over the bottom. There is no bow contribution to drag.

It has been found that the flow which separated from the chine may reattach to the side of the prismatic hull at some distance forward of the transom for certain combinations of C_v, β, τ and mean wetted length-beam ratio λ. An empirical formulation and confirming test data for defining the extent of side wetting are given in Figure 1. The slope of the line through the data is:

$$\lambda_{c_1} - \lambda_{c_2} = C_v^2 \sin\tau \qquad (1)$$

To define the operating conditions for the chines dry case, λ_{c_2} should be equal to zero. From the wetted area relations given in Reference 1, it can be shown that:

$$\lambda_{c_1} = \lambda - \frac{1}{2\pi} \frac{\tan\beta}{\tan\tau} \qquad (2)$$

Thus, for chines-dry planing of a prismatic form, it is necessary that

$$C_v^2 = \frac{\lambda - 0.16 \tan\beta/\tan\tau}{3 \sin\tau} \qquad (3)$$

This formulation is conservative for typical planing hull forms where the transom beam is smaller than the maximum beam and where the sides are not vertical as for the prismatic models, but have tumblehome.

The trim of a planing craft usually attains its maximum value, referred to as hump trim, at speed coefficients of approximately 1.5 to 2.0. As the speed increases, the trim decreases again and the wetted keel length increases. Depending upon the load and LCG position, the bow may again become immersed when the speed coefficient is sufficiently high. The planing equations of Reference 1 can be used to determine the velocity and load conditions when bow immersion will reoccur. In these high-speed cases, the bow drag increment is relatively small since the large rise of the boat's center of gravity assures only small immersions of the bow.

It has been observed that the planing performance predictive techniques of Reference 1 provide reasonably realistic results at these high speeds.

e) Summary: Figure 2 illustrates quantitatively some of the planing and non-planing features described above. The smooth water resistance and trim are plotted versus volume Froude number $(F_{n\nabla} = V/\sqrt{g\nabla^{1/3}})$ for the L/B = 2 hull (Model 4665) of Series 62 planing forms (Reference 3). $F_{n\nabla}$ is used as the absicca since it is the speed coefficient used by Clement and Blount in Reference 3. For this case, $F_{n\nabla} \sim 1.5\ C_v$.

The unshaded areas on these plots indicate the speed range where the wetted keel length, as measured in the model tests, is less than the LWL. The circles represent the trim and resistance as computed by the planing formulations of Reference 1. In the speed range where $L_K < LWL$, the bow is essentially clear of the water and there is good agreement between computed and measured results. For $F_{n\nabla}$ less than approximately 2.0 where $L_K > LWL$, so that the bow is immersed, the measured resistance is considerably larger than that predicted by the planing formulations, thus illustrating the large influence of bow immersion. This effect is particularly evident at the forward position of the LCG which exaggerates bow immersion.

At $F_{n\nabla}$ larger than approximately 4, when L_K is again larger than L_{WL} , the computed and measured resistance are reasonably in agreement, thus demonstrating the less serious effect of some bow immersion in this speed range. It is also to be noted that there is agreement between measured and computed trim angles in planing range when $F_{n\nabla} \geq 2.0$.

It appears then that the development of a resistance predictive procedure for transom-stern planing hulls for $F_{n\nabla} \leq 2.0$ is required if analytical predictions of performance are to be made over the entire speed regime. It is recognized, of course, that the installed horsepower for craft designed for maximum speed in the truly planing range will be considerably larger than for $F_{n\nabla} \leq 2.0$. However, the usual cruise speed of small military craft is in the range of $F_{n\nabla} \leq 2.0$. This is the speed range wherein the craft operates for most of its life and, hence, requires some rational design guidance in order to achieve low resistance for maximum fuel economy or for the selection of cruise engines separate from the main high-speed drive engines.

The subsequent sections of this paper are concerned with the development of an analytical procedure for resistance prediction in the non-planing speed range.

DESCRIPTIONS OF AVAILABLE METHODICAL SERIES

The development of the resistance-prediction equations has been based on published results of resistance tests carried out for several methodical series of transom-stern craft. These methodical series results afford the considerable advantage of being relatively well organized and documented and, hence, the information required such as hull form characteristics can be more readily obtained than is the case for most ad hoc model test results. Since applications are intended especially for relatively small high-speed craft, without skegs, certain series data which are felt to represent large moderate speed ships are not considered.

The chief characteristics of the model series are exhibited in Tables Ia-g. The descriptive information contained in these tables includes statement of authorship of the publication containing performance results for the series (complete information on the source publication is given in the list of references); a tabulation of the range of values of geometric characteristics of the models of the series; a brief description of the number, construction and size of models used, together with information concerning turbulence stimulation, if used, and the range of speeds used for the tests; location and size of test facility; the figure number in this report which contains the body plan, bow and stern profiles and design waterline endings for the parent form of the series; remarks concerning the characteristics of the hull forms and the expected operational regimes of the craft; a brief description of the manner in which results are presented; the friction correction method is noted, and, a listing of other related investigations besides resistance testing.

The tabulations of ranges of geometric characteristics of the seven series covered are combined in a separate Table II for convenience in making comparisons. Complete listings of the geometric characteristics of each of the 118 models of the several series used in deriving the resistance-prediction equations are given in Tables IIIa-g. Nomenclature is in accord with the ITTC standard listing.

Complete listings of the resistance characteristics derived for each of the 118 models used are presented in Table IVa-g for total resistance, in terms of lb/lb-displacement for a 100,000-lb craft in 59°F S.W., with $C_A = 0.0$, and in Table Va-g for residuary resistance, lb/lb-displacement. Values are given for eleven values of volume Froude number, $F_{n\nabla}$, 1.0,1.1,1.2,...,2.0, which are considred to cover the interesting non-planing speed range for virtually all of the vessel forms concerned. The 1947 ATTC (Schoenherr) friction coefficients were used for extrapolation from model to full size with one exception (noted in Table I): for the SSPA series, the residuary resistance coefficients presented by Lindgren and Williams[9] were determined using the 1957 ITTC friction coefficients. Over the range of speeds considered, the residuary resistance derived using the ITTC coefficients is lower than those derived with ATTC coefficients by less than about 2.5%. The difference in total resistance is less.

DERIVATION OF RESISTANCE EQUATIONS

The resistance results for the 118 models of the seven different series of transom stern hull forms have been analyzed to derive a statistically-based correlating equation which can be used to estimate the resistance of other forms in the early stages of design.

PREVIOUS ANALYSES

Doust[12] first applied the method of statistical analysis of resistance data to trawler hull forms, using data for all trawler models tested in Tank No.1, National Physical Laboratory, Teddington, England. The residuary resistance coefficients were curve-fitted at four speed-length ratios, $V/\sqrt{L}$ = 0.80, 0.90, 1.0, and 1.0, deriving equations by the method of least-squares which express the resistance as a function of six form parameters [L/B, B/T, C_M, C_P, LCB/L_{pp}(%) and i_e]. The equations derived contain 30 coefficients for each speed parameter. The resulting equation produces predictions of good accuracy compared with model tests: "the differences between measured and calculated resistance coefficients ($C_{TL} = R_T L/\Delta V^2$, for 200-ft L_{pp} vessels) were less than 3% for 95% of the cases except for $V/\sqrt{L}$ = 1.00, where the rate of change of C_{TL} with $V/\sqrt{L}$ is quite high, and the differences here were within 5% for 85% of the cases.

Doust has also applied the method of least squares to analyze propulsion data for trawlers[12,13] and resistance and propulsion data for random high-speed merchant vessel forms.[14] This type of analysis has also been applied by Sabit to data of related forms including Series 60,[15] and the British Ship Research Association[16] methodical series of merchant ship forms.

A very interesting analysis has been undertaken by van Oortmerssen[17] of the Netherlands Ship Model Basin in which the speed dependence of the resistance is incorporated according to some concepts given by Havelock.[18] In this way a single equation can be derived which is valid over a range of speeds, compared with the method of Doust in which a separate equation is required for each speed. An additional advantage is that it may be expected that some extrapolation beyond the speed range of the input data may be permissible since the speed dependence of this equation is theoretically-based. Application of this method to random data for small ships such as trawlers and tugs resulted in an equation which gives predictions of lesser accuracy than those reported by Doust.[12,13] The differences between measured and calculated resistance are less than 12% for 90% of the cases.

For the present analysis, Doust's type of analysis, i.e., a separate equation for separate values of the speed parameter, is applied rather than van Oortmerssen's. The reason for this is that theoretical analyses do not provide comparable guidance for the speed-dependence of the wave-making resistance of transom-stern craft, as they do for conventional stern vessels.

The present analysis is intended to cover the hump drag regime which generally corresponds with the last and largest hump in the curve of wave resistance versus Froude number which exhibits significant oscillations (humps and hollows) over the lower speed range. At higher speeds the craft will either achieve a planing attitude or drive through the water in a displacement mode with an approximately constant wave-resistance coefficient substantially less than the maximum hump value.

Particularly useful guidance to the analysis of resistance of small, transom-stern craft in this speed range has been given by Nordstrom[7] whose observations were reviewed and extended by Clement.[19] Nordstrom found that for this speed range, the resistance per lb displacement for a given value of volume Froude number $F_{n\nabla} = V/\sqrt{g\nabla^{1/3}}$, is most strongly dependent on the slenderness ratio, $L/\nabla^{1/3}$ is, indeed, a highly important parameter in regard to the hump resistance. The dependence on other parameters in addition to a more complete exposition of dependence on $L/\nabla^{1/3}$ is determined by this study.

DATA AND EQUATIONS USED IN PRESENT ANALYSIS

The total resistance, lb per lb displacement, for eleven Froude numbers, $F_{n\nabla}$ = 1.0, 1.1, ..., 2.0, given in Table IVa-g for the 118 models of seven series were used to derive equations relating the resistance to some of the hull form parameters listed in Tables IIIa-g.

For the shorter, fuller forms used (e.g., Series 62,63), the residuary part of the resistance dominates the total resistance -- in some cases accounting for over 95% of the total, while for the longer, finer forms (e.g., Series 64), the frictional resistance predominates -- in some cases accounting for 75% of the total. Since R_R/Δ is especially small for these slender forms, it was found to be difficult to curve-fit equations which produced good approximations of the R_R/Δ values for the slender forms. It was decided to curve-fit R_T/Δ since equations could be obtained which give reasonably good approximations of the measurements for this case. Since the R_T/Δ values correspond to ships with displacements of 100,000-lb S.W. at 59^oF with $C_A = 0.0$, corrections ought to be applied for other conditions of displacements, C_A, etc., which depend on the hull's wetted surface. Methods will be shown later for estimating the wetted surface and for making these corrections, which are usually not very important except for rather slender craft.

Four parameters were selected for inclusion in the resistance estimating equation:

1. $L_{WL}/\nabla^{1/3}$ -- since Nordstrom has demonstrated its importance.
2. $C_\Delta = \Delta/wB_X^3 = \nabla/B_X^3$ -- since planing performance (particularly rough-water performance) is strongly affected by this parameter and may be expected to have significance for high sub-planing speed
3. i_e -- waterline half entrance angle, since preliminary graphical correlations suggested this parameter to be preferable to L/B.
4. A_T/A_X -- ratio of transom area to maximum section area since hydrostatic and hydrodynamic considerations indicate the separation of flow at the transom may produce an increment of resistance (cavity drag), this parameter is included.

Additional parameters which are known to have substantial effects on resistance in some speed ranges are omitted in the present case for particular reasons. The LCG locations are generally not varied for the methodical series whose results are being used for this analysis. However, several of the models of the different series have been tested with varying LCG locations and results suggest that the reported data (re-presented here in

Tables IV and V) correspond to optimum or near-optimum LCG conditions. An approximate method for correcting resistance predictions to other LCG positions is presented in Appendix B, based on results of tests on Series 62 hard-chine models (Reference 3) and Series 63 round-bilge forms (Append A). Other parameters, such as deadrise angle and hard-chine or round-chine shape, which are important for planing speeds, are felt to be of lesser significance for this lower speed range. A complete presentation of the relationships amongst hull form parameters for the 118 hull forms will be given with a discussion of the range of applicability of the derived equation in the next section.

Actually, $\nabla^{1/3}/L_{WL}$ was used in the analysis because the resulting equations, especially with reduced numbers of terms, gave slightly more favorable fits to the data. Inspection of Nordstrom's resistance correlations suggests that $R_T/\Delta \sim \text{constant}/(L_{WL}/\nabla^{1/3})$, very approximately. The waterline half-entrance-angle, i_e, enters the equations as $\sqrt{2i_e}$, a form suggested by the preliminary graphical analysis. The symbols used in the curve-fitted equations are denoted:

$$
\begin{aligned}
X &= \nabla^{1/3}/L_{WL} \\
Z &= \nabla/B_X^3 \\
U &= \sqrt{2i_e} \\
W &= A_T/A_X
\end{aligned}
\qquad (4)
$$

All dimensions used in forming these coefficients should correspond to waterline measurements from the lines plan at the stillwater (V = 0) draft and trim. B_X and A_X are the maximum waterline breadth and section area, respectively, which, in general, do not occur directly amidships.

Least-squares curve-fitting was applied, starting vi a general 27-term equation, viz.,

$$
\begin{aligned}
R_T/\Delta = {} & A_1 + A_2X + A_3Z + A_4U + A_5W + A_6XZ + A_7XU + A_8XW + A_9ZU + A_{10}ZW + A_{11}UW + A_{12}X^2 + A_{13}Z^2 \\
& + A_{14}U^2 + A_{15}W^2 + A_{16}XZ^2 + A_{17}XU^2 + A_{18}XW^2 + A_{19}ZX^2 + A_{20}ZU^2 + A_{21}ZW^2 + A_{22}UX^2 \\
& + A_{23}UZ^2 + A_{24}UW^2 + A_{25}WX^2 + A_{26}WZ^2 + A_{27}WU^2
\end{aligned}
\qquad (5)
$$

and terms which were of small significance eliminated until further elimination of terms produced a significant degradation of the goodness of fit, as judged by a) the average of the absolute value of the per cent difference between the measured and calculated resistance, and b) by the square root of the sum of the squares of the differences. Figure 10 shows the variations of these parameters as a function of the number of terms retained in the course of arriving at equations for $F_{n\nabla} = 1.5$. Two calculating schemes were used: in the first, the least-squares method was used to minimize the magnitude of the differences between the measured and calculated resistances, while in the second, the method was used to minimize the percentage differences. In both cases the elimination of terms results in the same terms remaining in the reduced equations but the coefficients are slightly different. For $F_{n\nabla} = 1.5$, the goodness of fit is only slightly affected by reduction in number of terms unless fewer than about 10 terms are used.

FINAL PREDICTION EQUATION (Δ = 100,000 LB)

A reduction of number of terms retained for the equations is desirable for two reasons: a) with more terms, the equations may "fit" the data better yet give a poorer interpolation formula for use in ad hoc cases, since the dependence on the parameters will in general be less "smooth" with more terms, and b) the equations adopted, while not trivial, may be calculated without excessive difficulty with the help of a modern electronic desk calculator (having memory registers, preferably) in lieu of a programmed computer — if only a few cases are required. The equations selected for the eleven $F_{n\nabla}$'s involve 14 terms:

$$R_T/\Delta = A_1 + A_2X + A_4U + A_5W + A_6XZ + A_7XU + A_8XW + A_9ZU + A_{10}ZW + A_{15}W^2 + A_{18}XW^2 + A_{19}ZX^2 + A_{24}UW^2 + A_{27}WU^2 \quad (6)$$

Values for the coefficients are given in Table VI for a displacement of 100,000 lbs. Some of the 14 terms are omitted in each instance and in no case are more than 13 terms required. These equations and coefficients are based on the scheme of minimizing the percentage difference between measured and calculated resistances.

Range of Applicability

An empirically-based resistance equation may be used to estimate the resistance of craft whose characteristics fall within the range of characteristics embodied in the models whose resistance data were applied to derive the equation. Attempts to estimate resistance of craft which do not have such characteristics must be considered speculative to a greater or lesser extent. This warning, which is given by all authors who have developed empirical resistance-estimating equations, is perhaps especially relevant for small-craft applications where designers often adopt "unorthodox" hull lines, either by choice or because of exigencies of design.

Hull Proportions and Loading

The range of characteristics of the models used in the development of the present resistance-estimating equations are exhibited in the complete tabulations of hull geometric characteristics given in Tables IIIa-g. To assist in determining whether a given hull form comes within the range of parameters represented by the models which were used to derive Eq.(6), plots of the various parameters are given in Figures 11-16.

Relation Between i_e and $L_{WL}/\nabla^{1/3}$

Figure 11 shows the relationship between these two important parameters for the series models used. The bold enclosing line indicates the recommended limits of applicability of Eq.(6). In general, for slender forms ($L_{WL}/\nabla^{1/3} > 8$) entrance angles should be low while for fuller forms, entrance angles may be rather high owing to the inclusion of the Series 62 data.

Relation Between A_T/A_X and $L_{WL}/\nabla^{1/3}$

The plot of A_T/A_X versus $L_{WL}/\nabla^{1/3}$ given in Figure 12 shows that in the middle range of $L_{WL}/\nabla^{1/3}$'s, A_T/A_X cannot be too low and for larger $L_{WL}/\nabla^{1/3}$'s, A_T/A_X must be near 0.42. Again, Series 62 accounts for extreme values of A_T/A_X, as well as i_e, for lower range of $L_{WL}/\nabla^{1/3}$.

Relation Between C_Δ and $L_{WL}/\nabla^{1/3}$

The loading coefficient C_Δ may be expressed in terms of the length-beam ratio and $L_{WL}/\nabla^{1/3}$, in the form

$$C_\Delta = \left(\frac{L_{WL}}{B_X}\right)^3 \left(\frac{\nabla^{1/3}}{L_{WL}}\right)^3 \tag{7}$$

$L_{WL}/\nabla^{1/3}$ is shown plotted as a function of L_{WL}/B_X for the models of interest in Figure 13. A convenient relationship between the parameters may be expressed as

$$L_{WL}/\nabla^{1/3} = 3.5 + 0.50\left(\frac{L_{WL}}{B_X}\right) \pm 1.5 \tag{8}$$

from which it is possible to determine whether the loading coefficient for a given design falls within the required range circumscribed by the limits for the series forms.

As shown in Figure 14 the following combinations of A_T/A_X and i_e are applicable to Eq.(5):

$$\begin{array}{ll}
A_T/A_X & i_e \\
0.41 - 0.42 & 4 - 27.5 \\
0.52 & 11 - 27.5 \\
0 - 0.70 & 15 - 27.5 \\
0.70 - 0.90 & 25^\circ + 150\left[\left(\frac{A_T}{A_X} - 0.70\right)\right] \pm 10
\end{array} \tag{9}$$

For the special cases introduced by the Series 64 and SSPA forms (A_T/A_X = 0.41 and 0.42) and the NPL models (A_T/A_X = 0.52), the range of i_e versus A_T/A_X is extended to somewhat lower values while Series 62 accounts for most of the large transom area ratios as well as waterline entrance angles.

Relation Between C_Δ and i_e

This relationship is expressed in Figure 15 in the form of L_{WL}/B_X vs. i_e, recalling the relation between C_Δ and (L_{WL}/B_X) $(\nabla^{1/3}/L_{WL})$, Eq.(7).

Again, a bold line envelopes a region of L_{WL}/B_X (hence, C_Δ) vs. i_e for which Eq.(6) is expected to apply.

Relation Between C_Δ and A_T/A_X

Figure 16 presents L_{WL}/B_X plotted against A_T/A_X for all of the models whose resistance data were used to derive Eq.(6). A bold line envelopes the region of applicability of Eq.(6).

It should be borne in mind that the parameters involved in the resistance equation may not be sufficient to assume that an ad hoc craft is, in fact, "orthodox," in the sense that the equation may be applied reliably: the figures showing body plans and bow and stern shapes provide further guidance. Consideration of the diversity of forms shown by these plans indicates that the limitations of orthodoxy required of a design are not inflexibly circumscribed, but rather free.

As more experience is accumulated in using Eq.(6) to predict resistance for ad hoc hull forms and comparisons made with model test results for these forms, it may be possible to modify the limits of applicability depicted in Figures 11-16. For the present time these limits, which preclude substantial extrapolations outside the range of parameters used to derive Eq.(6), are recommened.

Froude Number

The range of volume Froude number, $F_{n\nabla} = V/\sqrt{g\nabla^{1/3}}$, for which Eq.(6) applies, is between 1.0 and 2.0. Coefficients of the equation are tabulated in Table VI for eleven specific Froude numbers: 1.0, 1.1, 1.2, ..., 2.0.

Longitudinal Center of Gravity

Figure 17 shows the values of $\overline{LCG}/L_{pp}$, for all of the models of the seven series employed to derive Eq.(6) as a function of $L_{WL}/\nabla^{1/3}$. For this range of LCG locations, between 2 and 7 percent of L_{pp} aft of midships, the resistance of these models is nearly minimum, only slightly dependent on LCG position.

Appendix B contains a brief and approximate analysis of the influence of variations in LCG position on resistance as a function of $F_{n\nabla}$, $L_{WL}/\nabla^{1/3}$ and i_e. Equations are derived based on data for Series 62[3] models which have full bow waterline endings and hard chines together with some new data for Series 63 models (included in Appendix A) which have somewhat finer bow waterline endings and round bilges. These equations are based on less data than Eq.(6) and, hence, are considered to be rather less reliable for predictions but can still be expected to provide useful design guidance.

Accuracy of Prediction Equation

The total number of resistance data points in the "nose planing" range was 1285 for 118 models at 11 values of $F_{n\nabla}$ (some model tests did not extend to the highest speeds). The distribution of the error in prediction of the low speed resistance is given in Figure 18. The distribution appears to be approximately normal. The differences between measured and calculated resistance are less than 10% for 90% of the cases.

Corrections for Other Displacements

Results are given by the Eq.(6) which applies to craft with 100,000 lb displacement in sea water at 59°F, based on Schoenherr's friction coefficients with correlation allowance C_A=0.0 . For other values of displacement, water conditions, C_A, or friction coefficients, the results can be corrected according to the relation

$$\left(\frac{R_T}{\Delta}\right)_{corr} = \left(\frac{R_T}{\Delta}\right)_{100,000} + \left[(C_F' + C_A) - C_{F_{100,000}}\right] \frac{1}{2} \frac{S}{\nabla^{2/3}} F_{n\nabla}^2 \qquad (9)$$

where

$\left(\frac{R_T}{\Delta}\right)_{corr}$ = corrected value of R_T/Δ

$\left(\frac{R_T}{\Delta}\right)_{100,000}$ = value of $\frac{R_T}{\Delta}$ for Δ = 100,000-lb SW, from Eq.(6)

$C_{F_{100,000}}$ = Schoenherr friction coefficient corresponding to

$$R_n = \frac{F_{n\nabla}\left(\frac{L}{\nabla^{1/3}}\right)\sqrt{32.2 \times \frac{100,000}{64}}}{1.2817 \times 10^{-5}}$$

C_F' = friction coefficient for corrected displacement, water conditions, etc.

S = wetted surface

The indicated correction will be small (perhaps insignificant) for many cases, especially for low values of $L/\nabla^{1/3}$, where the residuary resistance dominates the frictional component, which is common in the hump-drag speed range. Tabulated information in Tables IV and V gives guidance on the proportion of residuary to frictional resistance for the models used. The correction may be significant for slender forms having low values of residuary resistance and relatively high wetted surface. The wetted surfaces for the models used, having transom sterns, may be estimated from the following equation which was derived from an analysis of the stillwater values for the models of the series

$$S/\nabla^{2/3} = 2.262\sqrt{\frac{L_{WL}}{\nabla^{1/3}}}\left[1 + 0.046\,\frac{B_X}{T} + 0.00287\left(\frac{B_X}{T}\right)^2\right] \qquad (10)$$

which predicts S within ±9% for 95% of the cases used.

An alternative formula for estimating wetted surface presented by Marwood and Silverleaf[20] is

$$S/\nabla^{2/3} = \left(\frac{L_{WL}}{\nabla^{1/3}}\right)^2\left(1.7\,\frac{B_X}{L_{WL}} \times \frac{T}{B_X} + \frac{B_X}{L_{WL}}\,C_B\right) \qquad (11)$$

which exhibits a dependence on block coefficient.

PLANING RESISTANCE EQUATIONS

For the speed range where the craft is truly planing, i.e., when the flow has separated from the chines and transom and the wetted hull length is less than L_{WL} so that there is emergence of the bow, computational methods are available for prediction of hull performance in smooth and rough water.[1,2,21] Although these predictive techniques are concerned with prismatic hull forms (constant beam, constant deadrise, buttocks parallel to the hull), they have been successfully applied to actual hull forms by proper selection of an "effective" constant deadrise and beam. Savitsky[1] presents a procedure for predicting the smooth-water equilibrium conditions of a planing hull. This work has been programmed for high-speed computers and is generally available to the small boat naval architect. Hadler[2] extends this work to include the effects of appendages and the direct and induced flow effects of propellers. Unfortunately, a computer program for this extended configuration is not yet generally available to the small boat naval architect. Fridsma[21] presents the results of a systematic study of the effects of deadrise, trim, loading, length-beam ratio, speed, and sea state on the performance of a series of prismatic planing hulls operating in irregular waves. The results of these parametric studies are summarized in design charts which enable predictions to be made of the motions, added resistance and impact accelerations of planing hulls in a seaway.

These planing hull computational proceedings are not reproduced in this report since they are readily available to the small boat designer in other publications. The application of these techniques to the hydrodynamic development of a planing hull designed for rough-water operation is demonstrated by Savitsky, Roper, and Benen.[22]

When these planing prediction techniques are combined with non-planing resistance equations of the present study, the small boat designer has available a procedure for predicting planing hull resistance for a wide speed range. The application of this combined procedure to series hulls and arbitrary hulls is demonstrated in the subsequent sections of this report.

APPLICATION

RESULTS FOR SERIES MODELS

Comparisons of the calculated resistances with the measured values for the NPL series at three values of $F_{n\nabla}$, viz., 1.1, 1.5 and 1.9, in Figures 19a,b and c, respectively, illustrate the dependence of resistance on the geometric characteristics varied in the series as well as showing the extent to which the results agree. The "carpet" plot is used so that curves of iso-$L_{WL}/\nabla^{1/3}$ against $U = \sqrt{2i_e}$ can be shown as well as the iso-U curves against $L_{WL}/\nabla^{1/3}$, which are similar to the correlations originally presented by Nordstrom[7] for small craft. While the correlation between measured and calculated resistance is generally satisfactory, the undulations exhibited in the original model data are not reflected in the calculated results. However, the dependence of resistance on U (which depends, for the NPL series, on L/B) as well as $L_{WL}/\nabla^{1/3}$ is apparent.

Resistance results for two Series 62 models at the nominal standard LCG condition are compared in Figures 20a and b with calculations according to the non-planing equation. Also shown are results according to the planing equation,[1] which is applicable over the high-speed range of operation. It is gratifying to note the relatively good continuity of the two calculation methods for conditions where they overlap, or nearly overlap, in speed range around $F_{n\nabla} = 2.0$ (see especially Figure 20a).

The effect of variation in LCG position on the resistance of the shortest, heaviest model of Series 62 are given in Figure 21. Calculated results from the resistance-estimating equation, corrected according to the recommended approximate method (Appendix B), are shown as well as results from the planing equation.

RESULTS FOR ARBITRARY CRAFT

Predictions of the resistances for several craft which were not used in developing the resistance-estimating Eq.(6) are compared with test results in Figures 22a to f. Predictions according to Eq.(6) have been corrected to correspond to the conditions for which these ad hoc test results were expanded. Hull form characteristics and displacement of these craft are given in the following Table VII.

TABLE VII

AD HOC HULL FORMS FOR WHICH COMPARISONS HAVE BEEN MADE BETWEEN MEASUREMENTS AND CALCULATIONS OF RESISTANCE

Designation	$L_{WL}/\nabla^{1/3}$	C_Δ	i_e	A_T/A_X	Δ, lb	$S/\nabla^{2/3}$	Figure
Nordstrom, 30-III[r,1]	5.84	0.972	13.93	0.516	47,400	6.45	22a
Nordstrom, 44-f[h,1]	7.33	0.491	7.36	0.33	60,300	6.00	22b
DL-1888[h,2]	5.16	0.228	26.80	0.612	10,000	6.87	22c
DTMB 4315[h,3]	5.50	0.291	18.40	0.65	10,000	7.45	22d
Series 50[h,4]	7.10	0.208	17.70	0.47	100,000	-	22e
Series 50[h,4]	6.34	0.171	21.40	0.47	100,000	-	22e
DL-A[h]	6.63	0.436	17.30	0.60	380,800	7.46	22f

Footnotes:
r round bilge
h hard-chine
1 From Ref. 7
2 From SNAME Small Craft Data Sheet No. 4
3 From SNAME Small Craft Data Sheet No. 10
4 From DL Files and Ref. 23

The degree of agreement between the measurements and calculated resistances is similar to what might be expected on the basis of the results for the series models used to derive the equations. Calculations according to Eqs.(6) for Model 4315 exhibit very large discrepancies; however, the LCG for this model is significantly aft of the nominal "normal" value. A correction for this effect based on the analysis for the influence of LCG described by Appendix B, assuming standard $\frac{\overline{LCG}}{L_{pp}}$ = 0.045 aft of ⊗ compared to 0.105 aft of ⊗ for Model 4315 yields improved correlation.

The effects of variations in ship size on predicted (extrapolated) R_T/Δ, associated with skin-friction coefficient variations, are exhibited in Figures 23-a to c, for the NPL Series Parent Model 100-A as well as a short, full Series 62 Model and a very long and slender Series 64 Model. It is seen that finer ships, having relatively large wetted surface and low residuary resistance, show substantial effects of variations of ship displacement. The percentage change in R_T/Δ for increase in displacement by a factor of 10 at $F_{n\nabla} = 1.5$ is: -5% before NPL Model 100-A ($L_{WL}/\nabla^{1/3}$ = 6.585), -1.5% for Series 62 Model 4662-111 ($L_{WL}/\nabla^{1/3}$ = 3.60), and -12% for Series 64 model 4813 ($L_{WL}/\nabla^{1/3}$ = 12.40). The influence of correlation allowance, C_A, on predicted R_T/Δ is evidently rather more important than variations in displacement, amounting to about 10% increase for $C_A = 0.4 \times 10^{-3}$ (a commonly used value) for NPL model 100-A, but this correction can be made quite simply (see Eq.3) when a value for C_A is selected.

INFLUENCE OF FORM PARAMETERS ON RESISTANCE

Equations (6) can be used to investigate the effects on resistance of variations of the hull form parameters $L_{WL}/\nabla^{1/3}$, C_Δ, i_e and A_T/A_X. A first approximation of the effects of variations could be obtained from the linear term of a Taylor's expansion, i.e.,

$$\delta R_T/\Delta = \frac{\partial R_T/\Delta}{\partial y} \delta y \tag{13}$$

where y is a hull form parameter and $\frac{\partial R_T/\Delta}{\partial y}$ can be derived for any parameter $y(= L_{WL}/\nabla^{1/3}$, for instance) from Eq.(6) as relatively simple algebraic equations (one for each Froude number). The usefulness of this approach is limited, however, especially because of significant non-linearities in most of the equations, and it is recommended that the complete Eqs.(6) be used for the study of probable effects of modidications of design parameters. A design optimization procedure could, of course, be developed based on these equations but it is not clear whether this would be generally useful, especially since the pre-planing drag may be only one element of the overall performance capability of a craft. The development of such an optimization procedure is not pursued here.

The resistance-estimating equations have been exercised to evaluate the influence of variations of form parameters for a particular parent craft, corresponding to the parent form of the NPL series having characteristics given in Table VIII.

TABLE VIII

CHARACTERISTICS OF NPL MODEL 100A
(Parent Form For Example Calculation of Influence of Variations in Hull Form Parameters on R_T/Δ)

$L_{WL}/\nabla^{1/3}$	=	6.585
C_Δ	=	0.855
i_e	=	11 degrees
A_T/A_X	=	0.52

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Results are presented in Figures 24a to d showing the effects of variations over a wide range of the several parameters. The limits of applicability of the predictions, obtained by using the characteristics of NPL Model 100A given in Table VIII in conjunction with Figures 11-16, are shown in Figures 23a to d.

The following comments apply to the pre-planing speed range where $F_{n\nabla}$ lies between 1.0 and 2.0.

1) An increase of $L/\nabla^{1/3}$ results in a significant reduction in smooth water resistance. This effect is similar to that shown by Nordstrom[7].

2) C_{Δ} has little influence on resistance for these hull form characteristics. The dependence of R_T/Δ on C_{Δ} as approximated by Eqs.(2) is linear (but dependent on $L/\nabla^{1/3}$, i_e and A_T/A_X), is never very great and may show either an increase or decrease of R_T/Δ for increase of C_{Δ}, depending on values of the other form parameters.

3) Increasing i_e results in an appreciable increase of resistance. For example, at $F_{n\nabla} = 1.5$ a four degree increase in i_e to 15 deg (which is not by any means a large waterline entrance angle) produces an 8 percent increase in R_T/Δ. This calculated increase in resistance is corroborated by the data for this series shown in Figure 19-b. Since no data are available for forms with still lower i_e, for this value of A_T/A_X, the equation ought not to be applied for $i_e < 11$ degrees.

4) The use of Eq.(6) appears to indicate that the ratio of transom area to maximum section area is such as to produce a maximum resistance for the values of other hull form parameters selected. However, the range of applicability of the equation, limited by the fine waterline extrance (see Fig. 14) is not wide and the extreme variations of R_T/Δ obtained from the equation for values of A_T/A_X outside of the range 0.41 to 0.52 must not be considered significant. It must be pointed out that the dependence of R_T/Δ on A_T/A_X depends on $F_{n\nabla}$ as well as on the other

hull form parameters and more conclusive generalizations are not presently possible. Consequently, it is suggested that the dependence of R_T/Δ on A_T/A_X be investigated for each hull form evaluation to be carried out.

CONCLUSIONS

1. Based on the smooth water resistance data of seven transom-stern hull series, which included 118 separate hull forms, a statistically-based correlation equation is developed for predicting the resistance of these hull forms in the non-planing range.

2. The equation is a function of slenderness ratio ($L_{WL}/\nabla^{1/3}$); beam loading ($C_\Delta = \nabla/B_X{}^3$); waterline entrance angle (i_e); ratio of transom area to maximum section area (A_T/A_X); and volume Froude number ($F_{n\nabla} = V/\sqrt{g\nabla^{1/3}}$). The equations are applicable within the following range of combinations of hull and Froude number.

   (a) $1.0 < F_{n\nabla} < 2.0$

   (b) Hull form parameters and proportions delimited by the range of values for the 118 hull forms whose data were used to derive the equation, as illustrated in Figures 11-16.

   (c) $2\% \le \overline{LCG}/L_{PP} < 7\%$ aft of midship. Some additional guidance is given for wider variations in LCG position.

3. Within the above constraints, the influence of form and loading parameters is as follows:

   (a) $L_{WL}/\nabla^{1/3}$ is the most important form parameter, resulting in significant reductions in smooth water resistance as $L_{WL}/\nabla^{1/3}$ is increased.

   (b) C_Δ has little influence on resistance and may show either an increase or decrease of R_T/Δ for increase of C_Δ, depending on values of other form parameters.

   (c) As i_e is decreased, R_T/Δ is decreased.

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(d) An increase of A_T/A_X may produce either an increase or a reduction in R_T/Δ depending upon $F_{n\nabla}$ and other hull form parameters. The form of the equations suggests that an extremum, in most cases a maximum, of R_T/Δ exists for a certain value of A_T/A_X. The influence may be important and should be investigated for each case.

(e) With the range of $\overline{LCG}/L_{pp}$ between 0.2 and 0.7 aft of midship, the resistance is nearly constant, with the exception of some cases of short, full forms.

4. For $F_{n\nabla} > 2.0$, published planing equations appear adequate to provide resistance estimates for planing hulls wherein the flow separates from the transom and chines and there is emergence of the bow.

5. Formulations are given for the planing conditions which lead to complete flow separation from the chines and transom.

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REFERENCES

1. Savitsky, D., "Hydrodynamic Design of Planing Hulls," Marine Technology, Vol. 1, No. 1, Oct 1964, pp 71-95.

2. Hadler, J.B., "The Prediction of Power Performance on Planing Craft," Transactions Society of Naval Architects and Marine Engineers, Vol. 74, 1966, pp 563-610.

3. Clement, E.P. and Blount, D., "Resistance Tests of a Systematic Series of Planing Hull Forms." Transactions, SNAME, Vol. 71, pp 491-561, 1963.

4. Marwood, W.J. and Bailey, D., "Design Data for High-Speed Displacement Hulls of Round-Bilge Form." Ship Division, NPL, Report No.99, Feltham, England.

5. Marwood, W.J. and Bailey, D., "Transverse Instability of Round-Bottomed High-Speed Craft Underway," Ship Division, NPL, Report No. 98, Feltham, England.

6. Bailey, D., "Some Model Experiments with Transom Flaps Fitted to Round-Bottom Craft," Ship Division, NPL, Report No. 102, Feltham, England, September 1967.

7. Nordstrom, H.F., "Some Tests With Models of Small Vessels." Swedish State Shipbuilding Experimental Tank, Publ. No. 19, Göteborg, Sweden, 1951.

8. DeGroot, D., "Resistance and Propulsion of Motorboats," Netherlands Ship Model Basin. Publ. No. 93, Wageningen, The Netherlands (DTMB Translation 244, by W.B. Hinterthan, January 1956).

9. Lindgren, H. and Williams, A., "Systematic Tests with Small, Fast Displacement Vessels, Including a Study of the Influence of Spray Strips." Proceedings 1968, Diamond Jubilee Internat'l Mtg. SNAME.

10. Yeh, H.Y.H., "Series 64 Resistance Experiments on High-Speed Displacement Forms," Marine Technology, Vol. 2, No. 3, July 1965.

11. Beys, P.M., "Series 63 Round Bottom Boats," Davidson Laboratory, Stevens Institute of Technology, Report 949, April 1963.

12. Doust, D.J. and O'Brien, T.P., "Resistance and Propulsion of Trawlers." Transactions, North East Coast Institution of Engineers and Shipbuilders, Vol. 75, 1958-59.

13. Doust, D.J., "Optimized Trawler Forms." Transactions, NECIES, Vol. 79, 1962-63.

14. Doust, D.J., "An Assessment of N.P.L. Resistance Data on Ocean Going Ships." NPL Report No. 47, 1963.

15. Sabit, A.S., "A Tabulated Analytical Procedure Based on Regression Analysis for the Determination of the Form Coefficients and EHP for Ships Designed According to Series 60." European Shipbuilding, Vol. XX, No. 2, 1971.

16. Sabit, A.S., "Regression Analysis of the Resistance Results of the BSRA Series." International Shipbuilding Progress, Vol. 18, No. 197, 1971.

17. van Oortmerssen, G., "A Power Prediction Method and Its Application to Small Ships." International Shipbuilding Progress, Nov. 1971.

18. Havelock, T.H., "The Wave-Making Resistance of Ships: A Theoretical and Practical Analysis." Proceedings, Royal Society of London, A, Vol. 82, p 276, 1909.

19. Clement, E.P., "A Critical Review of Several Reports on Round-Bottom Boats," David Taylor Model Basin, Hydromechanics Laboratory Technical Note 40, July 1963.

20. Marwood, W.J. and Silverleaf, A., "Design Data for High Speed Displacement Type Hulls and A Comparison with Hydrofoil Craft." Third Symposium on Naval Hydrodynamics High Performance Ships, ONR-ACR-65, Sept. 1960.

21. Fridsma, G., "A Systematic Study of the Rough-Water Performance of Planing Boats, Irregular Waves, Part II," Davidson Laboratory, Stevens Institute of Technology Report 1495, March 1967.

22. Savitsky, D.; Roper, J.K. and Benen, L., "Hydrodynamic Development of a High-Speed Planing Hull for Rough Water." paper presented at Ninth ONR Symposium on Naval Hydrodynamics, Paris, August 1972.

23. Davidson, K.S.M. and Suarez, A., "Tests of Twenty Related Models of V-Bottom Motor Boats - EMB Series 50." DTMB Report R-47, March 1949.

TABLE 1a

SERIES: NPL (Round Bilge)

AUTHORS: Marwood and Bailey (Ref. 4)

GEOMETRIC PARTICULARS OF MODELS

$\frac{L_{WL}}{\nabla^{1/3}}$	C_Δ	i_e	C_B	C_P	C_{wp}	L_{WL}/B_X	B_X/T	$\frac{A_T}{A_X}$	$\frac{B_T}{B_X}$	$\frac{T_T}{T_X}$	$\frac{LCG}{L_{pp}}$
4.5, 5.0 5.5, 6.0 6.5, 7.0 7.5, 8.0 and 8.5	0.134 to 1.468	11 12.5 16.1 and 20.5	0.397	0.693	0.753	3.33 4.55 5.41 and 6.25	1.69 to 9.83	0.52	0.815	0.513	0.064 aft of

Model Characteristics

19 wood models, all with L_{WL} = 8.33 ft. Turbulence stimulation with studs 1/8" diam x 1/10" height, spaced 1" apart. Speed Range, $V/\sqrt{L}$ = 1.0 to 4.0 ($F_{n\nabla}$ = 0.3 to 1.2).

Test Facility

No.3 Tank, National Physical Laboratory, Feltham, England; 1300-ft long x 48-ft wide x 25-ft deep.

Body Plans: Figure 3

Remarks

This series deals solely with vessels intended to operate between F_{n_L} = 0.3-1.19 ($V/\sqrt{L}$ = 1.0-4.0). These vessels, therefore, do not operate in the pure planing region although they may overlap into it at the higher end of the speed range. The form has therefore been designed as a round-bilge hull. The characteristics of such a hull are:

- (a) fine straight lines forward
- (b) transom stern
- (c) the afterbody incorporates a rounded bilge section
- (d) the buttock lines in the afterbody are genera[illegible] straight with a small steady rise aft

Presentation

Resistance, lb/lb displacement, for models (corrected to standard water temperature of 15°C) are plotted as functions of L/B, $L/\nabla^{1/3}$ and Froude number.

(Cont'd)

Table 1a (Cont'd)

Cross-faired results were taken from curves for use in analysis. Curves of wetted surface underway, running trim and rise of CG are also given. Actual model data have been tabulated in a separate technical memorandum.

Friction Correction

1947 ATTC (Schoenherr), using wetted surface information from curves as fraction of Froude number, $C_A = 0.0$.

Related Work

1. Study of roll stability at certain speeds for some narrow-beamed models (Ref.5).
2. Study of effects of transom flaps on resistance for two models (Ref.6).

TABLE 1b

SERIES: Nordstrom (Round Bilge)

AUTHORS: Nordstrom (Ref.7)

GEOMETRIC PARTICULARS OF MODELS

$\frac{L_{WL}}{\nabla^{1/3}}$	C_Δ	i_e	C_B	C_P	C_{wp}	L_{WL}/B_X	B_X/T	$\frac{A_T}{A_X}$	$\frac{B_T}{B_X}$	$\frac{T_T}{T_X}$	$\frac{\overline{LCG}}{L_{pp}}$
5.65	0.518	15.1	0.373	0.576	0.725	4.83	3.57	0	0	0	0.0179
to	to	to	0.390	0.589	to	to	3.34	0.6	0.66	0.10	0.0249 &
7.72	0.877	22.5	and	and	0.761	6.94	and	and	and	and	0.0288
			0.410	0.599			3.16	0.13	0.72	0.15	aft of)(

Model Characteristics

3 wood models, with lengths from 2m to 2.5m; no turbulence stimulation. Speed Range, $F_{n\nabla}$ = 0.5 to 2.1 .

Test Facility

Royal Institute of Technology, Stockholm; 60m long x 3m wide x 1.35m deep.

Body Plans: Figure 4

Remarks

Three models with differing $L/\nabla^{1/3}$, each tested at three different displacements with level trim (at V=0).

Presentation

DeGroot (Ref.8) has presented residuary resistance coefficients, C_R , as function of $V/\sqrt{L}$.

Friction Correction

Original publication (Ref.7) gave resistance for full size displacement extrapolated by Froude coefficients. Results given by DeGroot are re-analyzed according to 1947 ATTC with C_A = 0.0.

TABLE 1c

SERIES: Deb [illegible] (Round Bilge)
AUTHOR: D[illegible] (Ref.8)

GEOMETRIC PARTICULARS OF MODELS

$\frac{L_{WL}}{\nabla^{1/3}}$	C_Δ	i_e	C_B	C_P	C_{wp}	L_{WL}/B	B_X/T	$\frac{A_T}{A_X}$	$\frac{B_T}{B_X}$	$\frac{T_T}{T_X}$	$\frac{LCG}{L_{pp}}$
5.23 to 7.75	0.550 to 1.039	13.5 to 22.4	0.421 0.437 and 0.457	0.650 0.661 and 0.677	0.787 to 0.796	4.55 to 7.39	3.57 3.34 and 3.16	0.17 0.23 and 0.30	0.75 0.78 and 0.79	0.18 0.24 and 0.29	0.016 0.02158 0.0264 aft of ☊

Model Characteristics

4 wood models, with lengths around 4 feet. No turbulence stimulation. Speed Range, $V/\sqrt{L}$ = 0.6 to 3.8 ($F_{n\nabla}$ = 0.18 to 1.1).

Test Facility

Delft Institute of Technology, Delft; 318-ft long x 13.8-ft wide x 8.27-ft deep (length has been extended to 466-ft since tests). Some high-speed data from NSMB, Wageningen; 830-ft long x 34.5-ft wide x 18-ft deep.

Body Plans: Figure 5

Remarks

Four models with differing $L/\nabla^{1/3}$, each tested at three different displacements with level trim (at V=0). Some tests at the lightest displacement with trim by the bow (these results were not used for the present analysis).

Presentation

Residuary resistance coefficients, C_R, as function of $V/\sqrt{L}$.

Friction Correction

1947 ATTC (Schoenherr) with C_A = 0.0.

TABLE 1d

SERIES: SSPA (Round Bilge)

AUTHORS: Lindgren and Williams (Ref.9)

GEOMETRIC PARTICULARS OF MODELS

$\frac{L_{WL}}{\nabla^{1/3}}$	C_Δ	i_e	C_B	C_P	C_{wp}	L_{WL}/B_X	B_X/T	$\frac{A_T}{A_X}$	$\frac{B_T}{B_X}$	$\frac{T_T}{T_X}$	$\frac{\overline{LCG}}{L_{pp}}$
6 7 and 8	0.616 to 0.821	8.24 to 14.4	0.40	0.68	0.73	4.623 to 8.213	3 3.5	0.42 & 4	0.77	0.41	0.0415 aft of 𝔛

Model Characteristics

9 paraffin wax models, with lengths in the range 3.3 to 4.4m. Turbulence stimulation by 1mm diam tripwire 1/40 of length from F.P. Speed Range, $V/\sqrt{L}$ = 1.0 to 4.3 ($F_{n\nabla}$ = 0.3 to 1.3) .

Test Facility

Swedish State Shipbuilding Experimental Station. Goteborg; 240m long x 10m wide x 5m deep.

Body Plans: Figure 6

Remarks

The parent form is based on a series of fast torpedo boats built for the Swedish Navy.

"(a) Straight V-formed transverse sections in forebody.
(b) Round bilges along the whole hull with reduced bilge radius going aft.
(c) Docking keel from Sta.16 aft following the baseline BL .
(d) Relatively wide and deep transom stern.
(e) Deadrise angle in transom stern is small but is successively increased going forward."

Presentation

Residuary resistance coefficient, C_R , as function of F_{nL} .

Friction Correction

C_R derived from model tests with 1957 ITTC was used, with 1947 ATTC (Schoenherr) used for full size (100,000-lb displacement) with C_A = 0.0.

[Cont'd]

Table 1d(Cont'd)

Related Work

Additional tests in waves reported in Ref.(9). Also, some results of resistance with spray strips and with change of LCG position are reported in Ref.(9) for high speeds only.

TABLE 1e

SERIES: Series 64 (Round Bilge)

AUTHOR: Yeh (Reference 10)

GEOMETRIC PARTICULARS OF MODELS

$\frac{L_{WL}}{\nabla^{1/3}}$	C_Δ	i_e	C_B	C_P	C_{WP}	L_{WL}/B_X	B_X/T	$\frac{A_T}{A_X}$	$\frac{B_T}{B_X}$	$\frac{T_T}{T_X}$	$\frac{\overline{LCG}}{L_{pp}}$
8.04 to 12.4	0.740 to 4.877	3.7 to 7.8	0.35 0.45 and 0.55	0.63	0.761	8.454 to 18.264	2,3 and 4	0.405	0.86	0.44 0.37 and 0.29	0.0656 aft of ⊗

Model Characteristics

27 wood models, all with L_{WL} = 10 feet; no turbulence stimulation.
Speed Range, $V/\sqrt{L}$ = 0.2 to 5.0 ($F_{n\nabla}$ = 0.06 to 1.49)

Test Facility

NSRDC deep-water basin, Washington, D.C.; 889-ft long x 51-ft wide x 22-ft deep.

Body Plans: Figure 7

Remarks

Quite slender hull forms developed based on information available at NSRDC for moderately high-speed displacement-type surface ships.

Presentation

Tabulations and curves of residuary resistance in lb/ton displacement as function of $V/\sqrt{L}$ and $\Delta/(0.01L)^3$. Curves of change of bow and stern level versus $V/\sqrt{L}$.

Friction Correction

1947 ATTC (Schoenherr) with C_A = 0.0.

TABLE 1-f

SERIES: Series 63 (Round Bilge)

AUTHOR: Beys (Ref. 11)

GEOMETRIC PARTICULARS OF MODEL

$\frac{L_{WL}}{\nabla^{1/3}}$	C_Δ	i_e	C_B	C_P	C_{wp}	L_{WL}/B_X	B_X/T	$\frac{A_T}{A_X}$	$\frac{B_T}{B_X}$	$\frac{T_T}{T_X}$	$\frac{\overline{LCG}}{L_{pp}}$
4.5 to 6.4	0.061 to 1.204	16.9 to 28.6	0.383 to 0.636	0.577 to 0.774	0.755 to 0.815	2.524 to 5.750	2.891 to 9.503	0.03 to 0.74	0.26 to 0.91	0.065 to 0.770	0.058 aft to 0.003 fwd of ⊗

Model Characteristics

5 wood models, all with L_{pp} = 3 ft. Turbulence stimulation by 0.04-in diam wire strut with depth equal to model draft towed 5-in ahead of F.P. Speed Range, ($F_{n\nabla}$ = 0.05 to 2.75).

Test Facility

No.1 Tank, Davidson Laboratory, Stevens Institute of Technology; 100-ft long x 9-ft wide x 4.5-ft deep (semi-circular cross section); some tests have been carried out in the lengthened (130-ft long) tank.

Body Plans: Figure 8

Remarks

Five models of round bottom utility boats each tested at several displacements with level trim (at V=0). Additional tests with varying LCG position are reported in the Appendix of the present report.

Presentation

Complete tabulations of model data, including resistance, wetted surface, underway, running trim and rise of CG. Diagrams of various results.

Friction Correction

1947 ATTC (Schoenherr), using measured wetted surface information, with C_A = 0.0.

Related Work

Tests with varied LCG reported in Appendix of this report.

TABLE 1g

SERIES: Series 62 (Hard Chine)

AUTHORS: Clement and Blount (Ref.3)

GEOMETRIC PARTICULARS OF MODELS

$\frac{L_{WL}}{\nabla^{1/3}}$	C_Δ	i_e	C_B	C_P	C_{wp}	L_{WL}/B_X	B_X/T	$\frac{A_T}{A_X}$	$\frac{B_T}{B_X}$	$\frac{T_T}{T_X}$	$\frac{\overline{LCG}}{L_{pp}}$
3.07 to 8.53	0.090 to 0.869	32.2 to 65.6	0.44 to 0.605	0.80 to 0.81	0.795 to 0.825	1.67 to 6.72	3.25 to 8.00	0.755 to 0.985	0.69 to 0.87	≈1.0	0.052 0.058 & 0.065 aft of

Model Characteristics

5 wood models, with L_{pp} of 3.912 ft for L/B=2, 5.987 ft for L/B=3.06 and 8 ft for others. Turbulence stimulation by 0.035-in diam tripwire for some tests with shortest model only. Speed Range, ($F_{n\nabla}$ = 0.2 to 6.0).

Test Facility

NSRDC high-speed tank, Washington, D.C.; 2968-ft long x 20-ft deep x 16-ft deep.

Body Plans: Figure 9

Remarks

Five models of hard chine planing boats each tested at several displacements and several LCG positions. Hull characteristics are:

"(a) The deadrise angle at the transom should be fairly high ($12\frac{1}{2}$-deg was selected).

(b) The after portion of the hull bottom should have a constant deadrise angle so that the high-speed planing area would be untwisted.

(c) The stern should be narrow, with the transom width equal to about 65 percent of the maximum chine width.

(d) The bow sections should be convex."

Presentation

Complete tabulations of model data, including resistance, wetted surface, underway, running trim and rise of CG. Diagrams of various results.

Friction Correction

1947 ATTC (Schoenherr) using measured wetted surface information, with C_A = 0.0.

Related Work

Results of some porpoising stability observations included in Ref.(3).

TABLE II. GEOMETRIC PARTICULARS OF MODELS

SERIES	$\frac{L_{WL}}{\nabla^{1/3}}$	C_Δ	i_e (deg)	C_B	C_P	C_{wp}	L_{WL}/B_X	B_X/T	$\frac{A_T}{A_X}$	$\frac{B_T}{B_X}$	$\frac{T_T}{T_X}$	$\frac{LCG}{L_{pp}}$
NPL	4.5, 5.0 5.5, 6.0 6.5, 7.0 7.5, 8.0 and 8.5	0.134 to 1.468	11 12.5 16.1 & 20.5	0.397	0.692	0.753	3.33 4.55 5.41 & 6.25	1.69 to 9.83	0.52	0.815	0.513	0.064 aft of ⊗
NORDSTROM	5.65 to 7.72	0.518 to 0.877	15.1 to 22.5	0.373 0.390 and 0.410	0.576 0.589 and 0.599	0.725 to 0.761	4.83 to 5.94	3.57 3.34 and 3.16	0 0.6 and 0.13	0 0.66 and 0.72	0 0.10 and 0.15	0.0179, 0.0249 & 0.0288 aft of ⊗
DEGROOT	5.23 to 7.75	0.550 to 1.039	13.5 to 22.4	0.421 0.437 and 0.457	0.650 0.661 and 0.677	0.787 to 0.796	4.55 to 7.39	3.57 3.34 and 3.16	0.17 0.23 and 0.30	0.75 0.78 and 0.79	0.19 0.24 and 0.29	0.016, 0.0215 & 0.0264 aft of ⊗
SSPA	6 7 and 8	0.616 to 0.821	8.24 to 14.4	0.40	0.68	0.73	4.623 to 8.213	3 3.5 & 4	0.42	0.77	0.41	0.0415 aft of ⊗
SERIES 64	8.04 to 12.4	0.740 to 4.677	3.7 to 7.8	0.35 0.45 & 0.55	0.63	0.761	8.454 to 18.264	2, 3 & 4	0.405	0.86	0.44 0.37 & 0.29	0.0656 aft of ⊗
SERIES 63	4.5 to 6.4	0.061 to 1.204	16.9 to 28.6	0.383 to 0.636	0.577 to 0.774	0.755 to 0.815	2.524 to 5.750	2.891 to 9.503	0.03 to 0.74	0.26 to 0.91	0.065 to 0.770	0.058 aft to 0.003 forward of ⊗
SERIES 62	3.07 to 8.53	0.090 to 0.869	32.2 to 65.6	0.44 to 0.605	0.80 to 0.81	0.795 to 0.825	1.87 to 6.72	3.25 to 8.00	0.755 to 0.985	0.69 to 0.87	≈1.0	0.052 0.058 & 0.065 aft of ⊗

TABLE III(a-c): GEOMETRIC CHARACTERISTICS OF ALL MODELS USED IN DERIVING RESISTANCE-ESTIMATING EQUATIONS

Model	$L_{WL}/\nabla^{1/3}$	i_e	C_B	C_P	C_M	C_{WP}	$\frac{L_{WL}}{B_X}$	$\frac{B_X}{T}$	$\frac{\overline{LCG}}{L_{PP}}$ % aft of ⊗	$\frac{A_T}{A_X}$	$\frac{B_T}{B_X}$	$\frac{T_T}{T_X}$
(a) NPL												
NPLA	4.50	20.5	0.397	0.693	0.573	0.753	3.33	3.26	6.40	0.52	0.82	0.51
NPLB	5.00	20.5	0.397	0.693	0.573	0.753	3.33	4.47	6.40	0.52	0.82	0.51
NPLC	5.50	20.5	0.397	0.693	0.573	0.753	3.33	5.96	6.40	0.52	0.82	0.51
NPLD	6.00	20.5	0.397	0.693	0.573	0.753	3.33	7.73	6.40	0.52	0.82	0.51
NPLE	6.50	20.5	0.397	0.693	0.573	0.753	3.33	9.83	6.40	0.52	0.82	0.51
NPLF	4.50	15.5	0.397	0.693	0.573	0.753	4.55	1.75	6.40	0.52	0.82	0.51
NPLG	5.00	15.5	0.397	0.693	0.573	0.753	4.55	2.40	6.40	0.52	0.82	0.51
NPLH	5.50	15.5	0.397	0.693	0.573	0.753	4.55	3.19	6.40	0.52	0.82	0.51
NPLI	6.00	15.5	0.397	0.693	0.573	0.753	4.55	4.14	6.40	0.52	0.82	0.51
NPLJ	6.50	15.5	0.397	0.693	0.573	0.753	4.55	5.27	5.40	0.52	0.82	0.51
NPLK	7.00	15.5	0.397	0.693	0.573	0.753	4.55	6.58	6.40	0.52	0.82	0.51
NPLL	5.00	12.5	0.397	0.693	0.573	0.753	5.41	1.70	5.40	0.52	0.82	0.51
NPLM	5.50	12.5	0.397	0.693	0.573	0.753	5.41	2.26	6.40	0.52	0.82	0.51
NPLN	6.00	12.5	0.397	0.693	0.573	0.753	5.41	2.93	5.40	0.52	0.82	0.51
NPLO	6.50	12.5	0.397	0.693	0.573	0.753	5.41	3.72	6.40	0.52	0.82	0.51
NPLP	7.00	12.5	0.397	0.693	0.573	0.753	5.41	4.65	6.40	0.52	0.82	0.51
NPLQ	5.50	11.0	0.397	0.693	0.573	0.753	6.25	1.69	6.40	0.52	0.82	0.51
NPLR	6.00	11.0	0.397	0.693	0.573	0.753	6.25	2.20	6.40	0.52	0.82	0.51
NPLS	6.50	11.0	0.397	0.693	0.573	0.753	6.25	2.79	6.40	0.52	0.82	0.51
NPLT	7.00	11.0	0.397	0.693	0.573	0.753	6.25	3.49	5.40	0.52	0.82	0.51
NPLU	7.50	11.0	0.397	0.693	0.573	0.753	6.25	4.29	6.40	0.52	0.82	0.51
NPLV	8.00	11.0	0.397	0.693	0.573	0.753	6.25	5.20	6.40	0.52	0.82	0.51
NPLW	8.50	11.0	0.397	0.693	0.573	0.753	6.25	6.24	5.40	0.52	0.82	0.51
(b) NORDSTROM												
431	7.72	15.1	0.373	0.576	0.648	0.725	6.94	3.57	1.79	0.00	0.00	0.00
432	7.36	15.8	0.390	0.589	0.662	0.748	6.83	3.34	2.49	0.06	0.66	0.10
433	7.06	16.4	0.410	0.599	0.684	0.761	6.75	3.16	2.88	0.13	0.72	0.15
591	6.95	17.5	0.373	0.576	0.648	0.725	5.92	3.57	1.79	0.00	0.00	0.00
592	6.63	18.3	0.390	0.589	0.662	0.748	5.83	3.34	2.49	0.06	0.66	0.10
593	6.36	19.1	0.410	0.599	0.684	0.761	5.77	3.16	2.88	0.13	0.72	0.15
601	6.18	20.7	0.373	0.576	0.648	0.725	4.96	3.57	1.79	0.00	0.00	0.00
602	5.80	21.5	0.390	0.589	0.662	0.748	4.89	3.34	2.49	0.06	0.66	0.10
603	5.65	22.5	0.410	0.599	0.684	0.761	4.83	3.15	2.88	0.13	0.72	0.15
(c) DEGROOT												
41	7.75	13.5	0.421	0.650	0.648	0.787	7.39	3.57	1.60	0.17	0.75	0.16
42	7.40	14.1	0.437	0.661	0.661	0.790	7.27	3.34	2.15	0.23	0.78	0.24
43	7.09	14.6	0.457	0.677	0.674	0.796	7.18	3.16	2.64	0.30	0.79	0.29
51	6.77	16.4	0.421	0.650	0.648	0.787	6.04	3.57	1.60	0.17	0.75	0.18
52	6.46	17.1	0.437	0.661	0.661	0.790	5.93	3.34	2.15	0.23	0.78	0.24
53	6.19	17.7	0.457	0.677	0.674	0.796	5.87	3.16	2.64	0.30	0.79	0.29
61	6.14	18.3	0.421	0.650	0.648	0.787	5.22	3.57	1.60	0.17	0.75	0.18
62	5.87	19.6	0.437	0.661	0.661	0.790	5.15	3.34	2.15	0.23	0.78	0.24
63	5.63	20.2	0.457	0.677	0.674	0.796	5.09	3.16	2.64	0.30	0.79	0.29
71	5.70	20.8	0.421	0.650	0.648	0.787	4.67	3.57	1.60	0.17	0.75	0.18
72	5.45	21.7	0.437	0.661	0.661	0.790	4.60	3.34	2.15	0.23	0.78	0.24
73	5.23	22.4	0.457	0.677	0.674	0.796	4.55	3.16	2.64	0.30	0.79	0.29

[Cont'd]

TABLE III(d-e) [Continued]

Model	$L_{WL}/\nabla^{1/3}$	i_e	C_B	C_P	C_M	C_{WO}	$\frac{L_{WL}}{B_X}$	$\frac{B_X}{T}$	$\frac{\overline{LCG}}{L_{PP}}$ % aft of ⊈	$\frac{A_T}{A_X}$	$\frac{B_T}{B_X}$	$\frac{T_T}{T_X}$
(d) SSPA												
1215A	6.00	14.4	0.400	0.680	0.590	0.730	4.62	3.00	4.15	0.42	0.77	0.41
1212A	6.00	11.5	0.400	0.680	0.590	0.730	5.82	3.50	4.15	0.42	0.77	0.41
1209A	6.00	9.5	0.400	0.680	0.590	0.730	7.12	4.00	4.15	0.42	0.77	0.41
1216A	7.00	13.5	0.400	0.680	0.590	0.730	4.94	3.00	4.15	0.42	0.77	0.41
1213A	7.00	10.8	0.400	0.680	0.590	0.730	6.23	3.50	4.15	0.42	0.77	0.41
1210A	7.00	8.9	0.400	0.680	0.590	0.730	7.61	4.00	4.15	0.42	0.77	0.41
1217A	8.00	12.6	0.400	0.680	0.590	0.730	5.34	3.00	4.15	0.42	0.77	0.41
1214A	8.00	10.3	0.400	0.680	0.590	0.730	6.73	3.50	4.15	0.42	0.77	0.41
1211A	8.00	8.2	0.400	0.680	0.590	0.730	8.21	4.00	4.15	0.42	0.77	0.41
(e) SERIES 64												
4784	8.04	5.5	0.550	0.630	0.873	0.761	11.96	2.00	6.55	0.41	0.86	0.44
4786	8.94	4.7	0.550	0.630	0.873	0.761	14.02	2.00	6.56	0.41	0.86	0.44
4789	10.46	3.7	0.550	0.630	0.873	0.761	17.73	2.00	6.56	0.41	0.86	0.44
4790	8.04	6.7	0.550	0.630	0.873	0.761	9.75	3.00	6.56	0.41	0.86	0.44
4791	8.94	5.8	0.550	0.630	0.873	0.761	11.45	3.00	6.56	0.41	0.86	0.44
4792	10.46	4.5	0.550	0.630	0.873	0.761	14.46	3.00	6.56	0.41	0.86	0.44
4793	8.04	7.8	0.550	0.630	0.873	0.761	8.45	4.00	6.56	0.41	0.86	0.44
4794	8.94	6.6	0.550	0.630	0.873	0.761	9.91	4.00	6.56	0.41	0.86	0.44
4795	10.46	5.2	0.550	0.630	0.873	0.761	12.54	4.00	6.56	0.41	0.86	0.44
4796	8.50	5.5	0.450	0.630	0.714	0.761	11.96	2.00	6.56	0.41	0.86	0.37
4797	9.58	4.7	0.450	0.630	0.714	0.761	14.07	2.00	6.56	0.41	0.86	0.37
4798	11.26	3.7	0.450	0.630	0.714	0.761	17.93	2.00	6.56	0.41	0.86	0.37
4799	8.50	6.7	0.450	0.630	0.714	0.761	9.76	3.00	6.56	0.41	0.86	0.37
4800	9.58	5.8	0.450	0.630	0.714	0.761	11.49	3.00	6.56	0.41	0.86	0.37
4801	11.26	4.5	0.450	0.630	0.714	0.761	14.64	3.00	6.56	0.41	0.86	0.37
4802	8.50	7.8	0.450	0.630	0.714	0.761	8.45	4.00	6.56	0.41	0.86	0.37
4803	9.58	6.6	0.450	0.630	0.714	0.761	9.95	4.00	6.56	0.41	0.86	0.37
4804	11.26	5.2	0.450	0.630	0.714	0.761	12.68	4.00	6.56	0.41	0.86	0.37
4805	9.35	5.5	0.350	0.630	0.556	0.761	11.96	2.00	6.56	0.41	0.86	0.29
4806	10.46	4.7	0.350	0.630	0.556	0.761	14.15	2.00	6.56	0.41	0.86	0.29
4807	12.40	3.7	0.350	0.630	0.556	0.761	18.26	2.00	6.56	0.41	0.86	0.29
4808	9.35	6.7	0.350	0.630	0.556	0.761	9.76	3.00	6.56	0.41	0.86	0.29
4809	10.46	5.8	0.350	0.630	0.556	0.761	11.55	3.00	6.56	0.41	0.86	0.29
4810	12.40	4.5	0.350	0.630	0.556	0.761	14.91	3.00	6.56	0.41	0.86	0.29
4811	9.35	7.8	0.350	0.630	0.556	0.761	8.45	4.00	6.56	0.41	0.86	0.29
4812	10.46	6.6	0.350	0.630	0.556	0.761	10.00	4.00	6.56	0.41	0.86	0.29
4813	12.40	5.2	0.350	0.630	0.556	0.761	12.91	4.00	6.56	0.41	0.86	0.29

[Cont'd]

TABLE III(f-g)[Continued]

Model	$L_{WL}/\nabla^{1/3}$	i_e	C_B	C_p	C_M	C_{wp}	$\frac{L_{WL}}{B_X}$	$\frac{B_X}{T}$	$\frac{\overline{LCG}}{L_{PP}}$ % aft of ⊗	$\frac{A_T}{A_X}$	$\frac{B_T}{B_X}$	$\frac{T_T}{T_X}$
(f) SERIES 63												
47811	6.40	17.4	0.549	0.740	0.742	0.806	5.75	4.34	5.43	0.60	0.91	0.63
47812	5.60	21.8	0.594	0.745	0.797	0.813	5.59	3.36	5.33	0.70	0.91	0.73
47813	5.15	25.3	0.636	0.774	0.822	0.815	5.48	2.89	5.80	0.74	0.90	0.77
47801	6.40	16.9	0.512	0.690	0.742	0.797	4.92	5.59	3.55	0.46	0.88	0.51
47802	5.60	20.5	0.571	0.701	0.815	0.806	4.78	4.39	4.22	0.59	[illegible]	0.63
47803	5.15	23.8	0.597	0.735	0.812	0.810	4.70	3.69	5.05	0.67	0.91	0.70
47804	4.80	27.7	0.625	0.764	0.815	0.813	[illegible]	3.21	4.94	0.72	0.90	0.74
47771	6.40	17.2	0.462	0.647	0.714	0.786	[illegible]	7.14	3.11	0.28	0.75	0.35
47772	5.60	20.3	0.508	0.677	0.750	0.796	3.98	5.66	4.21	0.44	0.88	0.50
47773	5.15	23.3	0.530	0.695	0.753	0.801	3.86	4.88	4.65	0.54	0.90	0.59
47774	4.80	25.9	0.560	0.712	0.787	0.807	3.81	4.24	4.31	0.62	0.91	0.65
47775	4.50	28.6	0.584	0.734	0.796	0.810	3.76	3.76	4.95	0.66	0.91	0.69
47791	6.40	18.8	0.393	0.591	0.565	0.757	3.31	9.50	0.00	0.03	0.26	0.07
47792	5.60	21.5	0.430	0.620	0.694	0.777	3.14	7.66	2.39	0.25	0.64	0.29
47793	5.15	23.4	0.466	0.639	0.729	0.782	3.05	6.84	3.34	0.32	0.81	0.38
47794	4.80	25.0	0.499	0.659	0.757	0.786	2.99	6.18	4.38	0.40	0.83	0.45
47795	4.50	27.5	0.520	0.690	0.774	0.791	2.95	5.44	4.63	0.47	0.88	0.53
47782	5.60	22.6	0.383	0.577	0.664	0.775	2.70	9.20	-0.30	0.08	0.37	0.10
47783	5.15	24.5	0.412	0.601	0.685	0.781	2.63	8.19	2.39	0.18	0.57	0.23
47784	4.80	26.3	0.435	0.613	0.710	0.785	2.57	7.33	2.75	0.27	0.73	0.33
47785	4.50	27.9	0.464	0.642	0.723	0.789	2.52	6.64	3.40	0.34	0.82	0.41
(g) SERIES 62												
46651	3.07	65.5	0.575	0.810	0.710	0.825	1.67	4.60	6.50	0.92	0.85	1.00
46652	3.60	63.3	0.510	0.805	0.630	0.800	1.91	6.40	6.50	0.96	0.85	1.00
46653	4.09	60.6	0.460	0.800	0.570	0.795	1.95	7.55	6.50	0.97	0.87	1.00
46654	4.49	58.4	0.440	0.805	0.550	0.800	2.01	8.00	6.50	0.98	0.87	1.00
46661	3.84	56.7	0.595	0.810	0.735	0.825	2.83	4.15	5.80	0.83	0.78	1.00
46662	4.51	54.1	0.530	0.810	0.650	0.810	2.90	5.55	5.80	0.86	0.76	1.00
46663	5.08	51.1	0.490	0.800	0.595	0.800	2.96	7.10	5.80	0.90	0.76	1.00
46664	5.60	49.5	0.450	0.800	0.560	0.795	3.02	7.70	5.80	0.91	0.76	1.00
46672	5.25	47.0	0.550	0.810	0.680	0.820	3.84	5.10	5.20	0.79	0.69	1.00
46673	5.92	45.[illegible]	0.495	0.800	0.620	0.800	3.92	6.60	5.20	0.83	0.70	1.00
46674	6.52	42.5	0.460	0.800	0.575	0.795	3.99	7.50	5.20	0.85	0.70	1.00
46682	6.08	39.9	0.575	0.810	0.710	0.820	5.14	4.65	5.20	0.77	0.95	1.00
46683	6.86	38.9	0.515	0.810	0.640	0.805	5.24	6.05	5.20	0.80	0.69	1.00
46684	7.56	37.1	0.475	0.800	0.590	0.800	5.33	7.10	5.20	0.84	0.70	1.00
46692	6.79	34.0	0.590	0.810	0.730	0.825	6.40	4.25	5.20	0.76	0.70	1.00
46693	7.74	33.0	0.540	0.810	0.685	0.810	6.60	5.50	5.20	0.78	0.69	1.00
46694	8.53	32.2	0.490	0.800	0.610	0.800	6.72	6.75	5.20	0.81	0.69	1.00

TABLE IV: (a-c) TOTAL RESISTANCE VALUES FOR ALL MODELS USED IN DERIVING RESISTANCE-ESTIMATING EQUATION. TABULATED NUMBERS ARE 100 R_T/Δ (lb/lb) FOR 100,000 LB CRAFT IN 59°F SEA WATER. 1947 ATTC (SCHOENHERR) FRICTION COEFFICIENTS WITH C_A = 0.0, USED FOR SHIP R_R/Δ FROM TABLES V.

	$F_{n\nabla}$										
MODEL	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
(a) NPL											
NPLA	5.02	9.24	10.65	11.29	11.42	11.32	11.14	11.89	11.51	13.82	14.22
NPLB	4.60	7.05	8.78	9.64	10.09	10.24	10.48	10.76	11.11	11.46	11.85
NPLC	3.93	5.80	7.07	8.20	8.56	9.04	9.25	9.63	9.99	10.60	11.01
NPLD	3.70	5.26	6.31	7.36	7.88	8.37	8.77	9.07	9.51	10.11	10.59
NPLE	3.70	4.56	5.64	6.99	7.58	8.10	8.76	9.16	9.63	10.14	10.56
NPLF	5.45	8.01	10.19	10.36	10.61	10.62	10.75	10.79	11.22	11.61	11.98
NPLG	3.79	6.29	8.42	9.19	9.63	9.86	10.04	10.19	10.42	10.76	10.74
NPLH	3.39	5.10	6.90	7.94	8.53	8.85	9.15	9.38	9.65	9.77	9.92
NPLI	2.25	4.42	5.76	6.49	7.25	7.57	7.89	8.32	8.59	9.05	9.31
NPLJ	2.64	3.87	4.85	5.56	6.25	6.69	7.14	7.55	7.97	8.35	8.87
NPLK	2.52	3.45	4.20	4.89	5.63	6.15	6.75	7.15	7.57	8.07	8.53
NPLL	4.00	6.29	7.87	8.67	9.18	9.65	10.01	10.21	10.37	10.61	10.98
NPLM	3.33	5.11	6.55	7.87	8.32	8.74	9.11	9.36	9.55	9.92	10.18
NPLN	2.87	4.65	5.69	6.62	7.27	7.61	7.89	8.34	8.69	9.07	9.23
NPLO	2.64	3.46	4.50	5.22	6.05	6.43	6.73	7.40	7.71	8.16	8.47
NPLP	2.45	3.11	3.90	4.49	5.13	5.70	6.24	6.66	7.13	7.55	7.84
NPLQ	2.84	4.81	6.61	7.33	7.80	8.05	8.41	8.55	9.20	9.39	9.73
NPLR	2.54	4.00	5.52	6.42	6.98	7.34	7.75	8.09	8.45	8.75	9.13
NPLS	2.33	3.32	4.55	5.23	5.80	6.36	6.81	7.29	7.61	8.02	8.36
NPLT	2.22	2.87	3.89	4.44	4.95	5.50	6.01	6.48	6.90	7.34	7.61
NPLU	2.09	2.65	3.37	4.02	4.61	5.20	5.63	6.09	6.55	6.94	7.25
NPLV	2.07	2.51	3.15	3.73	4.36	4.99	5.43	5.89	6.34	6.78	7.23
NPLW	1.96	2.40	3.00	3.47	4.20	4.89	5.36	5.85	6.32	6.79	7.37
(b) NORDSTROM											
431	1.45	2.10	3.05	4.00	4.70	5.30	5.85	6.30	6.75	7.15	7.50
432	1.55	2.35	3.40	4.35	5.10	5.75	6.30	6.75	7.15	7.60	8.00
433	1.80	2.75	3.75	4.65	5.40	6.00	6.50	6.95	7.35	7.65	7.95
591	1.45	2.95	4.20	5.10	5.90	6.55	7.05	7.50	7.95	8.30	8.55
592	2.15	3.40	4.50	5.55	6.40	7.00	7.45	7.85	8.10	8.35	8.40
593	2.40	3.80	5.20	6.10	6.80	7.35	7.80	8.15	8.40	8.50	8.50
601	2.50	4.20	5.80	6.90	7.70	8.35	8.70	8.95	9.10	9.20	9.30
602	3.00	4.60	6.40	7.40	8.10	8.60	9.00	9.20	9.30	9.25	9.10
603	3.30	5.10	6.60	7.90	8.50	8.95	9.25	9.40	9.45	9.30	9.15
(c) DEGROOT											
41	1.95	2.50	3.50	4.45	4.95	5.40	5.85	6.30	6.80	7.25	7.75
42	2.00	2.70	3.60	4.45	4.85	5.25	5.75	6.30	6.85	7.40	7.90
43	2.10	3.00	3.95	4.60	5.00	5.50	6.00	6.50	7.10	7.70	
51	2.40	3.30	4.40	5.20	5.70	6.40	6.95	7.30	7.50	8.00	8.40
52	2.40	3.85	5.10	5.95	6.60	7.10	7.60	8.05	8.55	9.00	9.45
53	2.90	4.15	5.55	6.30	6.95	7.55	8.05	8.50	8.80		
61	2.95	4.25	5.75	6.60	7.25	7.75	8.15	8.40	8.55	8.90	9.40
62	3.10	4.50	6.05	6.85	7.50	8.05	8.40	8.55	8.78	8.80	
63	3.40	5.00	6.55	7.45	8.00	8.45	8.75	8.85	8.80		
71	3.45	4.60	6.00	7.55	8.40	8.95	9.33	9.70	10.00	10.15	10.20
72	3.90	6.10	7.60	8.65	9.40	9.95	10.40	10.75			
73	4.40	6.50	8.35	9.40	10.10	10.55	11.10	11.40			

[Cont'd]

TABLE IV: [Continued]
(d-e)

MODEL	$F_{n\nabla}$ 1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
(d) SSPA											
1215A	3.25	4.40	5.35	6.21	6.97	7.60	8.12	8.59	8.90	9.11	9.32
1212A	3.30	4.40	5.45	6.32	6.90	7.53	8.05	8.50	8.83	9.20	9.53
1209A	3.28	4.40	5.45	6.39	7.15	7.73	8.20	3.66	9.00	9.32	9.71
1216A	2.30	3.13	3.90	4.60	5.17	5.68	6.11	6.52	6.90	7.25	7.63
1213A	2.30	3.16	3.90	4.58	5.13	5.68	6.15	6.58	7.00	7.40	7.82
1210A	2.15	3.10	3.91	4.63	5.24	5.80	6.29	6.75	7.19	7.60	8.00
1217A	1.70	2.40	3.02	3.60	4.10	4.56	5.00	5.40	5.76	6.13	6.50
1214A	1.77	2.43	3.08	3.60	4.09	4.55	5.00	5.40	5.81	6.22	6.62
1211A	1.64	2.36	3.02	3.60	4.11	4.60	5.04	5.49	5.92	6.38	6.82
(e) SERIES 64											
4784	1.70	2.23	2.80	3.40	3.87	4.20	4.55	4.90	5.20	5.55	5.90
4788	1.60	2.00	2.30	3.03	3.50	3.85	4.25	4.60	4.90	5.20	5.50
4789	1.40	1.75	2.05	2.40	2.75	3.10	3.50	3.85	4.30	4.65	5.00
4790	1.70	2.20	2.65	3.15	3.85	4.10	4.60	5.00	5.45	5.90	6.25
4791	1.45	1.80	2.30	2.80	3.25	3.70	4.07	4.43	4.80	5.17	5.50
4792	1.40	1.55	1.95	2.25	2.65	3.05	3.50	3.85	4.20	4.60	4.95
4793	1.80	2.20	2.80	3.45	4.05	4.45	4.95	5.30	5.65	6.03	6.38
4794	1.65	2.00	2.40	2.90	3.60	4.00	4.45	4.90	5.30	5.70	6.10
4795	1.35	1.60	1.90	2.25	2.60	2.95	3.35	3.70	4.10	4.45	4.80
4796	1.45	1.90	2.40	2.90	3.35	3.75	4.15	4.50	[illegible]	5.10	5.40
4797	1.45	1.80	2.20	2.60	3.00	3.45	3.85	4.15	[illegible]	4.80	5.10
4798	1.20	1.40	1.70	2.00	2.35	2.70	3.05	3.30	3.60	3.95	4.30
4799	1.80	2.20	2.65	3.10	3.55	3.95	4.35	4.70	5.10	5.45	5.75
4800	1.35	1.65	2.00	2.40	2.85	3.35	3.70	4.00	4.30	4.60	4.95
4801	1.10	1.35	1.65	1.90	2.25	2.55	2.90	3.25	3.65	4.00	4.30
4802	1.50	1.90	2.35	3.00	3.50	3.95	4.35	4.75	5.05	5.35	5.70
4803	1.35	1.70	2.05	2.40	2.85	3.25	3.70	4.10	4.50	4.90	5.20
4804	1.30	1.50	1.75	2.05	2.35	2.70	3.05	3.40	3.75	4.10	4.40
4805	1.50	1.90	2.30	2.80	3.30	3.80	4.20	4.60	4.95	5.30	5.60
4806	1.35	1.70	2.00	2.35	2.75	3.20	3.65	4.05	4.45	4.85	5.15
4807	1.45	1.75	2.05	2.35	2.80	3.10	3.50	3.85	4.20	4.50	5.00
4808	1.55	1.90	2.25	2.70	3.15	3.65	4.05	4.45	4.80	5.20	5.65
4809	1.50	1.75	2.00	2.30	2.70	3.20	3.70	4.05	4.40	4.80	5.15
4810	1.35	1.60	1.80	2.00	2.30	2.70	3.20	3.75	4.20	4.70	5.20
4811	1.60	1.95	2.30	2.70	3.20	3.65	4.15	[illegible]	5.10	5.55	6.00
4812	1.50	1.80	2.10	2.50	2.90	3.30	3.80	4.30	4.70	5.15	5.50
4813	1.35	1.60	1.85	2.15	2.45	2.85	3.30	3.75	4.20	4.60	4.95

[Cont'd]

TABLE IV: [Continued]
(f-g)

MODEL	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
						$F_{n\nabla}$					
(f) SERIES 63											
47811	3.40	4.30	5.30	6.20	6.85	7.40	7.75	8.05	8.30	9.55	8.65
47812	3.85	5.30	6.85	8.00	8.55	8.90	9.15	9.35	9.55	9.80	10.05
47813	4.70	6.90	8.50	9.40	9.95	10.30	10.55	10.75	11.00	11.25	11.60
47801	3.10	4.00	5.15	6.15	6.90	7.40	7.90	8.30	8.65	9.00	9.40
47802	4.20	5.80	7.10	8.25	8.50	8.85	9.25	9.60	9.90	10.25	10.60
47803	4.60	6.90	8.40	9.40	9.90	10.20	10.50	10.75	11.05	11.40	11.85
47804	5.20	8.10	10.15	10.90	11.35	11.65	11.95	12.35	12.50	12.80	13.10
47771	3.65	4.70	5.85	6.75	7.50	8.10	8.65	9.15	5.45	9.80	10.20
47772	4.00	5.80	7.25	8.10	8.70	9.15	9.55	9.90	10.20	10.55	10.90
47773	4.80	6.80	8.70	9.70	10.15	10.50	10.75	10.95	11.15	11.40	11.70
47774	5.30	8.50	10.20	10.85	11.20	11.50	11.80	12.10	12.40	12.70	13.15
47775	6.40	10.00	11.70	12.50	13.00	13.05	13.20	13.40	13.70	14.00	14.35
47791	3.60	4.90	6.35	7.45	8.30	8.80	9.10	9.55	10.05	10.65	11.30
47792	4.10	6.10	7.85	8.70	9.30	9.70	10.10	10.50	11.00	11.60	12.20
47793	4.70	7.50	9.00	9.90	10.20	10.45	10.80	11.30	11.85	12.40	12.90
47794	6.50	9.20	10.60	11.05	11.35	11.85	12.00	12.40	12.75	13.25	13.85
47795	7.30	10.40	11.90	12.20	12.40	12.80	13.20	13.65	14.05	14.45	15.00
47782	4.25	6.80	8.40	9.30	9.60	10.15	10.45	10.70	11.00	11.50	11.95
47783	5.30	7.60	9.30	10.20	10.75	11.10	11.45	11.90	12.30	12.65	13.00
47784	6.20	9.80	11.30	11.95	12.10	12.40	12.70	12.95	13.20	13.50	13.70
47785	7.40	10.80	12.50	12.90	13.30	13.50	13.95	14.25	14.55	14.80	15.05
(g) SERIES 62											
46651	13.80	19.40	22.15	22.85	22.80	22.55	22.05	21.40	20.75	20.00	19.25
46652	10.70	15.55	18.25	18.20	17.50	17.20	16.95	16.63	15.25	15.80	15.40
46653	8.90	12.20	15.45	15.65	14.90	14.35	13.90	13.50	13.10	12.75	12.40
46654	8.90	17.40	14.45	14.75	14.20	13.65	13.25	12.90	12.45	11.93	11.35
46661	10.00	13.45	16.40	17.30	17.65	17.55	18.35	18.87	19.20	19.25	19.[illegible]
46652	8.05	10.85	12.90	13.65	13.80	13.90	14.00	14.10	14.25	14.45	14.60
46663	7.25	9.40	10.95	11.80	12.12	12.25	12.30	12.30	12.25	12.05	11.85
46664	6.25	8.00	9.45	10.10	10.20	10.35	10.76	11.10	11.25	11.20	11.00
46572	6.05	7.90	9.65	10.50	10.95	11.25	11.58	11.90	12.18	12.40	12.55
46673	5.25	6.75	8.10	8.90	9.35	9.70	9.95	10.20	10.45	10.75	11.00
46674	4.60	5.80	6.80	7.55	8.00	8.35	8.65	9.00	9.30	9.65	9.95
46682	4.55	5.85	7.00	8.00	8.70	8.93	9.00	9.25	9.05	10.00	10.40
46683	3.85	4.80	5.70	6.50	7.15	7.20	8.00	8.40	8.75	9.05	9.40
46684	3.50	4.25	5.05	5.75	6.30	6.70	7.00	7.40	7.90	8.35	8.80
46692	3.80	4.80	5.90	6.90	7.65	8.10	8.55	8.90	9.20	9.50	9.85
46693	3.35	4.10	4.80	5.55	6.10	6.60	7.05	7.50	7.90	8.30	8.70
46694	3.00	3.70	4.35	5.00	5.35	6.20	6.65	7.05	7.45	7.80	8.20

[Cont'd]

TABLE V: (a-c) RESIDUARY RESISTANCE VALUES FOR ALL MODELS USED IN DERIVING RESISTANCE-ESTIMATING EQUATION. TABULATED NUMBERS ARE 100 R_R/Δ (lb/lb) BASED ON 1947 ATTC (SCHOENHERR) FRICTION COEFFICIENTS EXCEPT FOR SSPA, WHICH ARE BASED ON 1957 ITTC LINE.

						$F_{n\nabla}$					
MODEL	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
(a) NPL											
NPLA	5.29	8.48	9.94	10.22	10.17	9.88	9.47	9.98	9.34	11.34	11.40
NPLB	3.89	6.20	7.76	8.46	8.71	8.65	8.66	8.58	8.74	8.78	8.81
NPLC	3.13	4.83	5.93	6.87	7.12	7.27	7.22	7.31	7.36	7.63	7.67
NPLD	2.80	4.18	5.02	5.86	6.15	6.37	6.50	6.51	6.63	6.88	6.98
NPLE	2.38	3.64	4.41	5.23	5.67	5.93	6.31	6.41	6.57	6.74	6.79
NPLF	4.88	7.31	9.37	9.40	9.49	9.34	9.29	9.12	9.34	9.49	9.60
NPLG	3.16	5.53	7.51	8.13	8.40	8.44	8.42	8.34	8.34	8.40	8.09
NPLH	2.51	4.26	5.92	6.79	7.20	7.33	7.40	7.39	7.40	7.25	6.99
NPLI	2.13	3.53	4.71	5.25	5.83	5.93	6.02	6.19	6.20	5.37	6.31
NPLJ	1.83	2.89	3.69	4.21	4.68	4.90	5.10	5.23	5.36	5.44	5.62
NPLK	1.61	2.34	2.69	3.36	3.86	4.12	4.44	4.53	4.64	4.79	4.88
NPLL	3.39	5.55	6.99	7.64	8.00	8.29	8.47	8.46	8.40	8.41	8.51
NPLM	2.58	4.32	6.02	6.78	7.07	7.30	7.46	7.50	7.56	7.57	7.53
NPLN	2.17	3.81	4.69	5.45	5.91	6.05	6.12	6.33	6.43	6.51	6.40
NPLO	1.88	2.54	3.42	3.96	4.60	4.81	4.82	5.25	5.29	5.45	5.45
NPLP	1.64	2.15	2.76	3.16	3.60	3.95	4.25	4.43	4.63	4.75	4.74
NPLQ	2.24	4.09	5.76	6.34	6.66	6.75	6.99	7.?8	?.33	7.30	7.38
NPLR	1.88	3.21	4.57	5.32	5.71	5.88	6.10	6.22	6.35	6.41	6.52
NPLS	1.61	2.45	3.52	4.04	4.42	4.79	5.02	5.29	5.37	5.52	5.60
NPLT	1.48	1.98	2.84	3.22	3.55	3.98	4.19	4.44	4.62	4.79	4.79
NPLU	1.30	1.70	2.25	2.72	3.12	3.50	3.70	3.93	4.13	4.24	4.26
NPLV	1.20	1.47	1.92	2.30	2.72	3.11	3.31	3.50	3.67	3.81	3.94
NPLW	0.93	1.23	1.63	1.88	2.37	2.80	2.99	3.19	3.35	3.40	3.71
(b) NORDSTROM											
431	0.70	1.35	2.00	2.75	3.30	3.70	4.00	4.30	4.50	4.60	4.70
432	0.85	1.50	2.45	3.15	3.70	4.20	4.50	4.80	5.00	5.20	5.35
433	1.10	1.90	2.80	3.50	4.?5	4.45	4.75	5.00	5.20	5.30	5.35
591	0.80	2.10	3.20	3.90	4.60	5.05	5.40	5.60	5.80	5.90	5.95
592	1.45	2.65	3.60	4.35	5.00	5.45	5.70	5.90	5.95	6.00	5.90
593	1.60	3.00	4.15	4.95	5.50	5.90	6.15	6.30	6.35	6.25	5.85
601	1.85	3.50	4.85	5.75	6.40	6.85	7.10	7.15	7.10	7.00	6.90
602	2.35	4.00	5.40	6.25	6.85	7.20	7.40	7.45	7.30	7.05	6.85
603	2.45	4.35	5.90	6.50	7.25	7.50	7.70	7.60	7.40	7.00	6.50
(c) DEGROOT											
41	1.10	1.65	2.45	3.15	3.50	3.75	4.00	4.?2	4.48	4.70	4.95
42	1.20	1.60	2.50	3.25	3.45	3.65	4.00	4.30	4.60	4.90	5.20
43	1.45	2.10	2.90	3.40	3.60	3.90	4.25	4.55	4.90	5.30	
51	1.60	2.50	3.40	3.95	4.45	4.80	5.15	5.35	5.42	5.50	5.75
52	1.80	3.00	4.10	4.75	5.25	5.55	5.90	6.15	6.40	6.60	6.85
53	2.15	3.40	4.50	5.20	5.70	6.10	6.45	6.65	6.80		
61	2.20	3.65	4.75	5.45	5.90	6.25	6.40	6.40	6.43	6.50	6.65
62	2.40	3.90	5.05	5.80	6.20	6.58	6.75	6.80	6.75	6.50	
63	2.75	4.25	5.60	6.30	6.75	7.05	7.45	7.08	6.85		
71	2.75	3.80	5.10	6.60	7.12	7.45	[illegible]	[illegible]	[illegible]	7.65	7.70
72	3.10	5.35	6.75	7.55	8.10	8.53	8.80	8.95			
73	3.55	5.60	7.40	8.30	8.85	9.30	9.55	9.70			

[Cont'd]

TABLE V: [Continued]
(d-e)

MODEL	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
						F_{nv}					
(d) SSPA											
1215A	2.40	3.45	4.30	5.02	5.60	5.97	6.40	6.60	6.68	6.64	6.70
1212A	2.62	3.45	4.30	4.92	5.58	6.02	6.32	6.43	6.52	6.68	6.82
1209A	2.69	3.48	4.33	5.10	5.75	6.12	[illegible]	6.72	6.78	6.85	7.00
1216A	1.45	2.15	2.75	3.30	3.70	4.05	4.28	4.50	4.62	4.70	4.85
1213A	1.52	2.20	2.78	3.30	3.68	3.98	4.20	4.49	4.60	4.75	4.92
1210A	1.40	2.10	2.72	3.28	3.70	4.08	4.35	4.60	4.80	4.95	5.12
1217A	0.85	1.40	1.90	2.28	2.60	2.82	3.09	3.12	3.25	3.35	3.52
1214A	0.90	1.40	1.80	2.12	2.45	2.72	2.98	3.18	3.32	3.48	3.62
1211A	0.80	1.32	1.80	2.20	2.52	2.75	2.88	3.20	3.40	3.56	3.72
(e) SERIES 64											
4784	0.95	1.40	1.85	2.20	2.50	2.70	2.85	2.95	3.05	3.15	3.20
4788	0.80	1.05	1.60	1.75	2.05	2.20	2.40	2.50	2.60	2.70	2.80
4789	0.60	0.75	0.93	1.05	1.25	1.40	1.60	1.75	1.88	1.95	2.05
4790	1.05	1.33	1.60	1.95	2.40	2.62	2.80	3.00	3.20	3.40	3.55
4791	0.70	0.90	1.20	1.50	1.80	2.00	2.20	2.40	2.60	2.65	2.75
4792	0.60	0.65	0.85	0.95	1.10	1.35	1.55	1.70	1.80	1.90	2.00
4793	1.05	1.35	1.75	2.20	2.55	2.85	3.10	3.25	3.35	3.50	3.62
4794	0.90	1.10	1.40	1.70	2.05	2.30	2.55	2.75	2.95	3.05	3.23
4795	0.55	0.60	0.65	0.90	1.05	1.20	1.35	1.45	1.60	1.70	1.75
4796	0.70	0.95	1.30	1.60	1.90	2.10	2.30	2.40	2.50	2.60	2.65
4797	0.70	0.85	1.05	1.25	1.50	1.70	1.90	2.00	2.10	2.15	2.17
4798	0.35	0.40	0.55	0.65	0.80	0.90	1.00	1.10	1.20	1.25	1.30
4799	0.95	1.20	1.50	1.80	2.10	2.35	2.55	2.70	2.85	2.90	2.95
4800	0.50	0.70	0.90	1.10	1.35	1.55	1.70	1.90	1.95	2.00	2.10
4801	0.30	0.35	0.40	0.50	0.60	0.75	0.90	1.00	1.10	1.20	1.25
4802	0.70	0.90	1.20	1.60	1.95	2.20	2.40	2.55	2.65	2.70	2.75
4803	0.50	0.60	0.80	1.00	1.30	1.50	1.70	1.85	1.98	2.02	2.10
4804	0.40	0.40	0.40	0.50	0.60	0.75	0.90	0.98	1.08	1.12	1.15
4805	0.70	0.90	1.15	1.45	1.75	1.98	2.15	2.30	2.40	2.50	2.60
4806	0.55	0.65	0.80	0.95	1.10	1.30	1.50	1.70	1.80	1.90	1.95
4807	0.55	0.60	0.70	0.80	0.95	1.05	1.20	1.30	1.40	1.50	1.60
4808	0.68	0.85	1.05	1.35	1.60	1.83	2.05	2.15	2.25	2.35	2.45
4809	0.55	0.60	0.70	0.90	1.05	1.20	1.40	1.60	1.70	1.80	1.90
4810	0.40	0.45	0.43	0.43	0.55	0.70	1.00	1.20	1.40	1.60	1.75
4811	0.70	0.85	1.00	1.25	1.50	1.80	2.00	2.25	2.40	2.55	2.70
4812	0.55	0.70	0.80	0.98	1.15	1.35	1.50	1.70	1.85	1.95	2.10
4813	0.35	0.40	0.45	0.50	0.60	0.75	0.90	1.00	1.15	1.25	1.35

[Cont'd]

TABLE V: [Continued]
(f-g)

	$F_{n\nabla}$										
MODEL	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
(f) SERIES 63											
47811	2.60	3.70	4.35	5.05	5.55	5.90	6.15	6.25	6.30	6.35	6.35
47812	3.05	4.70	6.10	7.05	7.45	7.60	7.65	7.70	7.70	7.75	7.75
47813	3.95	6.00	8.35	8.75	8.90	9.05	9.15	9.18	9.25	9.35	9.45
47801	2.25	3.10	4.25	4.85	5.35	5.85	6.05	6.30	6.45	6.55	6.70
47802	3.20	4.70	6.15	6.75	7.20	7.50	7.70	7.90	8.00	8.10	8.15
47803	3.75	6.35	7.95	8.60	8.80	8.90	9.00	9.15	9.25	9.40	9.70
47804	4.15	6.75	9.30	9.90	10.20	10.38	10.55	10.70	10.75	10.85	11.05
47771	2.65	3.50	4.50	5.45	5.90	6.45	6.80	7.00	6.90	9.80	6.90
47772	3.30	4.90	6.30	7.10	7.50	7.70	7.65	8.00	8.10	8.20	8.25
47773	4.10	6.55	7.95	8.65	8.90	9.05	9.18	9.25	9.25	9.25	9.30
47774	4.55	7.40	9.30	9.90	10.05	10.25	10.30	10.35	10.42	10.50	10.65
47775	5.00	9.10	10.95	11.65	11.90	11.75	11.65	11.75	11.90	12.00	12.20
47791	2.55	3.60	4.80	6.10	6.65	6.85	6.85	6.95	7.05	7.40	7.80
47792	3.20	5.00	6.70	7.40	7.75	7.90	8.05	8.20	8.50	8.75	9.10
47793	4.00	6.60	7.90	8.05	8.85	8.85	9.00	9.20	9.50	9.75	10.15
47794	6.00	8.40	9.75	10.10	10.15	10.20	10.25	10.40	10.60	10.90	11.00
47795	6.80	9.70	11.10	11.15	11.15	11.40	11.65	11.90	12.10	12.30	12.55
47782	3.60	5.90	7.00	7.70	8.10	8.30	8.30	8.25	8.25	8.35	8.60
47783	5.05	6.80	8.25	9.10	9.30	9.30	9.40	9.55	9.70	9.85	10.05
47784	5.20	8.20	10.10	10.50	10.70	10.80	10.90	10.95	10.45	10.95	10.95
47785	7.40	10.00	11.70	11.90	11.65	11.75	12.25	12.35	12.40	12.40	12.40
(g) SERIES 62											
46651	13.50	18.05	21.05	22.05	21.95	21.65	21.15	20.40	19.65	18.85	17.90
46552	10.05	14.20	17.10	17.45	16.90	16.05	15.65	15.20	14.85	14.20	13.70
46653	8.30	11.25	14.00	14.55	13.60	12.85	12.25	11.65	11.15	10.70	10.20
46654	8.10	10.70	12.75	13.50	12.80	11.95	11.30	10.80	10.20	9.40	8.65
46661	9.40	12.60	15.65	16.60	16.75	16.80	17.30	17.80	18.00	18.00	17.80
46662	7.35	10.00	11.95	12.65	12.60	12.60	12.60	12.55	12.65	12.80	12.80
46663	6.60	8.55	9.95	10.70	10.70	10.65	10.45	10.30	10.15	9.80	9.50
46664	5.25	6.85	8.45	8.90	8.60	8.25	8.45	8.75	8.80	8.50	8.15
46672	5.30	6.85	8.35	9.35	9.65	9.80	9.90	10.05	10.20	10.35	10.40
46673	4.50	5.80	7.00	7.70	8.05	8.10	8.00	7.95	7.95	8.00	9.10
46674	3.75	4.60	5.60	6.25	6.25	5.30	6.35	6.40	6.50	6.55	6.60
46682	3.90	5.05	6.10	6.90	7.33	7.50	7.50	7.45	7.50	7.75	8.00
46683	3.00	3.50	4.65	5.20	5.60	5.85	6.10	6.25	6.40	6.50	6.65
46684	2.65	3.30	3.90	4.40	4.65	4.80	4.90	5.10	5.25	5.45	5.55
46692	3.10	3.90	4.80	5.70	6.30	6.55	6.75	6.90	7.00	7.05	7.10
46693	2.55	3.15	3.70	4.10	4.45	4.75	4.95	5.10	5.30	5.50	5.60
46694	2.10	2.55	3.05	3.45	3.60	4.00	4.25	4.40	4.50	4.55	4.50

TABLE VI

COEFFICIENTS FOR RESISTANCE ESTIMATING EQUATION (6)

$X = \nabla^{1/3}/L_{WL}$ $U = \sqrt{2 I_e}$ $Z = C_\Delta = \nabla/B_X^3$ $W = A_T/A_X$

Coeff.	Multiples	$F_{n\nabla}=1.0$	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
A_1	1	0.06473	0.10776	0.09483	0.03475	0.03013	0.03163	0.03194	0.04343	0.05036	0.05612	0.05967
A_2	X	-0.48680	-0.88787	-0.63720	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A_4	U	-0.01030	-0.01634	-0.01540	-0.00978	-0.00664	0.0	0.0	0.0	0.0	0.0	0.0
A_5	W	-0.06490	-0.13444	-0.13580	-0.05097	-0.05540	-0.10543	-0.08599	-0.13289	-0.15597	-0.18661	-0.19758
A_6	XZ	0.0	0.0	-0.16046	-0.21880	-0.19359	-0.20540	-0.19442	-0.18062	-0.17813	-0.18288	0.20152
A_7	XU	0.10628	0.18186	0.16803	0.10434	0.09612	0.06007	0.06191	0.05487	0.05099	0.04744	0.04645
A_8	XW	0.97310	1.83080	1.55972	0.43510	0.51820	0.58230	0.52349	0.78195	0.92859	1.18569	1.30026
A_9	ZU	-0.00272	-0.00389	-0.00309	-0.00198	-0.00215	-0.00372	-0.00360	-0.00332	-0.00308	-0.00244	-0.00212
A_{10}	ZW	0.01089	0.01467	0.03481	0.04113	0.03901	0.04794	0.04436	0.04187	0.04111	0.04124	0.04343
A_{15}	W^2	0.0	0.0	0.0	0.0	0.0	0.08317	0.07366	0.12147	0.14928	0.18090	0.19769
A_{18}	XW^2	-1.40962	-2.46696	-2.15556	-0.92663	-0.95276	-0.70895	-0.72057	-0.95929	-1.12178	-1.38644	-1.55127
A_{19}	ZX^2	0.29136	0.47305	1.02992	1.06392	0.97757	1.19737	1.18119	1.01562	0.93144	0.78414	0.78282
A_{24}	UW^2	0.02971	0.05877	0.05198	0.02209	0.02413	0.0	0.0	0.0	0.0	0.0	0.0
A_{27}	WU^2	-0.00150	-0.00356	-0.00303	-0.00105	-0.00140	0.0	0.0	0.0	0.0	0.0	0.0
Average % Diff. between measured R_T/Δ & Eq. (5)		6.0	4.7	4.1	3.8	3.3	3.4	3.5	3.4	3.4	3.6	4.0
$\sqrt{\Sigma(\mathrm{Diff})^2}$		0.025	0.033	0.027	0.027	0.028	0.031	0.035	0.037	0.043	0.046	0.049

APPENDIX A

INFLUENCE OF LCG POSITION ON RESISTANCE OF SERIES 63 MODELS IN HUMP-DRAG REGION

Four models of the Series 63, round-bottom utility boat series, were tested in calm water to determine the influence of LCG position on resistance, change-of-trim and heave over the range of speeds where large wave-making resistance occurs.

The models tested in this program have nominal length-beam ratios of 3,4,5 and 6. A shorter, beamier model, having nominal L/B of 2.5 was not included in the present program. All of these models were built by the David Taylor Model Basin and had previously been tested for level-keel conditions at Davidson Laboratory. Full results of these tests and descriptions of the models have been given by Beys in Davidson Laboratory Report No. 949.[11] A 10-station body plan and waterline and profile endings are shown in Figure 8 of the present report.

The models were tested at two displacement conditions corresponding to nominal beam-draft ratios of 3.33 and 5.00. All tests were run in Davidson Laboratory Tank No. 1 (130'x9'x4.5'). Model resistance in the horizontal direction was measured with a stiff-spring element balance incorporating a linear-variable differential transformer whose output was recorded by integrating digital voltmeters at the tankside control station. The models were towed through a pivot box whose axis was on the assumed propeller shaft axis. A vertical force was applied through the pivot box and adjusted in magnitude so that the resultant towing force acted along the shaft line which had a 7.2 deg. slope relative to the baseline, the same as for the earlier tests reported in Reference 11. Trim and heave were measured with heave indicators at the FP and AP of the models. A 0.04-in. diameter wire strut, placed 5 inches ahead of the FP to a depth equal to the model draft, was used to stimulate turbulence. Photographs were taken of most of the test runs.

Model results are presented in Tables A-I to A-VI, covering the following conditions.

TABLE	MODEL	L/B (Nominal)	B/T (Nominal)
A-I	4781	6	3.33
A-II	4780	5	3.33
A-III	4777	4	3.33
A-IV	4780	5	5.00
A-V	4777	4	5.00
A-VI	4779	3	5.00

Model results of:

speed	VM	ft/sec
resistance	RM	lbs
Reynolds No.	REM	$VM \times L_{pp}/\nu$
Resistance Coefficient	CTM	$RM/\frac{\rho}{2}WA(VM)^2$
Trim	TRIM	deg
Heave of Sta.5(amidship)	HVE	in

are included, where ν = kinematic viscosity of water, ρ = mass density of water, and WA = wetted area of model. These results are also presented as dimensionless parameters:

Length Froude Number	FNL	$VM/\sqrt{gL}$
Volume Froude Number	FND	$VM/\sqrt{g\nabla^{1/3}}$
Residuary Resistance Coefficient	RROD	R_R/Δ
Total (Ship) Resistance Coeff.	RSOD	R_T/Δ

where $\nabla^{1/3}$ = (displaced volume)$^{1/3}$. Residuary and total (ship) resistance were calculated based on Schoenherr's (1947 ATTC) Friction formulation for model and hull. Ship predictions are for 100,000 lbs S.W. at 59°F with $C_A = 0$, comparable to the tabulations for Series 62 given by Clement and Blount.[3] The Reynolds number is based on L_{pp}, rather than measured mean wetted length, and the wetted area is assumed to be equal to the stillwater, level trim value, independent of speed and initial or running trim. For the speed range under consideration, these are reasonable approximations, and since the residuary resistance is such a dominant fraction of the total, the influence is considered unimportant.

TABLE A-1

Model 4781 L/B = 6 (Nominal) B/T = 3.33 (Nominal)

Model Characteristics: $L_{pp} = 3$ ft ; $\Delta = 9.21$ lbs F.W. at $77^{o}F$; W.A. = 1.74 ft^2

Scale Ratio = 16.75 for 100,000-lb ship in $59^{o}F$ S.W.; $C_A = 0$ for prediction of R_{ship}

VM ft/sec	RM lb	REM $\times 10^{-6}$	CTM $\times 10^{3}$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
TEST 1: LCG = 2.27-in aft amidships (level trim)									
3.98	0.343	1.241	12.85	0.65	-0.15	0.405	0.966	0.0250	0.0310
5.74	0.792	1.790	14.26	3.12	-0.05	0.584	1.393	0.0621	0.0741
7.53	1.008	2.348	10.55	3.50	0.10	0.766	1.827	0.0704	0.0902
9.32	1.202	2.907	8.21	3.20	0.21	0.949	2.262	0.0729	0.1024
4.65	0.596	1.450	16.36	2.24	-0.18	0.473	1.128	0.0484	0.0565
5.40	0.747	1.684	15.20	3.07	-0.12	0.550	1.310	0.0597	0.0704
3.59	0.256	1.120	11.79	0.62	-0.09	0.365	0.871	0.0176	0.0226
4.33	0.463	1.350	1[illegible].65	1.59	-0.10	0.441	1.051	0.0360	0.0430
4.96	0.669	1.547	16.14	2.54	-0.20	0.505	1.204	0.0543	0.0634
TEST 2: LCG = 4.07-in aft amidships									
4.65	0.719	1.450	19.73	3.83	-0.11	0.473	1.128	0.0618	0.0698
3.97	0.396	1.238	14.91	2.42	-0.08	0.404	0.963	0.0308	0.0368
5.40	0.868	1.684	17.66	4.57	-0.03	0.550	1.310	0.0729	0.0835
6.46	0.992	2.015	14.11	4.89	0.09	0.657	1.568	0.0781	0.0930
4.33	0.520	1.350	16.46	3.04	-0.09	0.441	1.051	0.0421	0.0492
7.53	1.101	2.348	11.52	4.92	0.25	0.766	1.827	0.0805	0.1003
TEST 3: LCG = 0.47-in aft am dships									
4.63	0.522	1.444	14.45	0.25	-0.30	0.471	1.124	0.0405	0.0485
3.98	0.317	1.241	11.88	-1.15	-0.25	0.405	0.966	0.0221	0.0282
5.40	0.708	1.684	14.41	0.94	-0.39	0.550	1.310	0.0555	0.0662
4.99	0.621	1.556	14.80	0.80	-0.31	0.508	1.211	0.0469	0.0581
6.47	0.852	2.018	12.30	1.78	-0.21	0.658	1.570	0.0646	0.0795
7.54	0.994	2.351	10.38	2.31	-0.18	0.767	1.830	0.0688	0.0836
TEST 4: LCG = 5.87-in aft amidships									
3.98	0.520	1.241	19.48	4.53	0.05	0.405	0.966	0.0442	0.0502
4.64	0.986	1.447	27.18	6.31	0.17	0.472	1.126	0.0908	0.0968
5.40	1.216	1.684	24.75	7.11	0.28	0.550	1.310	0.1106	0.1213
4.32	0.753	1.347	23.94	5.55	0.12	0.440	1.048	0.0675	0.0745
5.00	1.149	1.559	27.27	6.65	0.20	0.509	1.213	0.1061	0.1154

TABLE A-11

Model 4780 L/B=5 (Nominal) B/T=3.33 (Nominal)

Model Characteristics: L_{pp} = 3.00 ft ; Δ = 13.26 lbs F.W. at 76°F ; W.A. = 2.08 ft^2

Scale Ratio = 19.43 for 100,000-lb ship in 59°F S.W.;C_A=0 for prediction of R_{ship}

VM ft/sec	RM lb	REM $\times 10^{-6}$	CTM $\times 10^3$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
TEST 1: LCG = 2.27-in aft amidship (level trim)									
7.53	1.685	2.319	14.75	4.45	0.04	0.766	1.720	0.0945	0.1114
5.73	1.407	1.765	21.27	4.15	-0.16	0.583	1.309	0.0863	0.0964
11.11	2.382	3.422	9.58	6.23	0.53	1.131	2.537	0.1136	0.1484
3.25	0.264	1.001	12.41	0.08	-0.07	0.331	0.742	0.0128	0.0164
9.32	1.965	2.871	11.34	4.37	0.30	0.949	2.128	0.1018	0.1268
4.69	0.921	1.445	20.79	2.10	-0.32	0.477	1.071	0.0557	0.0627
8.59	1.858	2.646	12.70	4.19	0.15	0.874	1.962	0.1011	0.1226
3.97	0.458	1.223	14.43	0.64	-0.14	0.404	0.907	0.0244	0.0295
6.46	1.559	1.990	18.54	4.35	-0.09	0.657	1.475	0.0929	0.1056
8.95	1.887	2.757	11.69	4.35	0.25	0.911	2.044	0.0978	0.1210
11.50	2.840	3.542	10.56	7.06	0.63	1.170	2.626	0.1438	0.1810
10.02	2.154	3.086	10.65	4.92	0.31	1.020	2.288	0.1077	0.1364
TEST 2: LCG = 4.07-in aft amidship									
5.39	1.635	1.660	27.94	6.64	0.03	0.549	1.231	0.1056	0.1145
3.26	0.323	1.004	15.09	2.72	-0.00	0.332	0.745	0.0172	0.0208
4.69	1.138	1.445	25.59	5.25	0.05	0.477	1.071	0.0720	0.0790
6.46	1	1.990	22.15	7.30	0.38	0.657	1.475	0.1158	0.1285
3.98	[illegible]	1.226	17.52	3.20	-0.04	0.405	0.909	0.0319	0.0371
6.10	1.809	1.879	24.13	7.19	0.33	0.621	1.393	0.1142	0.1256
7.53	1.983	2.319	17.36	7.09	0.42	0.766	1.720	0.1170	0.1339
5.74	1.722	1.768	25.94	6.76	0.19	0.584	1.311	0.1100	0.1201
4.32	0.848	1.331	22.56	4.37	0.11	0.440	0.987	0.0521	0.0581
TEST 3: LCG = 5.87-in aft amidship									
4.32	1.028	1.331	27.34	6.83	0.09	0.440	0.987	0.0656	0.0716
3.26	0.396	1.004	18.50	5.03	0.10	0.332	0.745	0.0227	0.0263
5.73	2.215	1.765	35.50	9.83	0.41	0.583	1.309	0.1473	0.1574
6.45	2.289	1.987	27.31	10.38	0.70	0.656	1.473	0.1450	0.1607
5.39	2.138	1.660	36.53	9.71	0.36	0.549	1.231	0.1435	0.1525
5.02	1.829	1.546	36.03	9.11	0.39	0.511	1.146	0.1223	0.1302
4.69	1.483	1.445	33.47	8.09	0.22	0.477	1.071	0.0952	0.1050
3.98	0.697	1.226	21.84	6.34	0.37	0.405	0.909	0.0425	0.0475
TEST 4: LCG = 0.47-in aft amidship									
4.32	0.636	1.331	16.86	-1.53	-0.42	0.440	0.987	0.0360	0.0419
3.26	0.255	1.004	11.96	-2.15	-0.25	0.332	0.745	0.0122	0.0157
5.72	1.396	1.765	21.11	1.69	-0.41	0.583	1.309	0.0855	0.0956
6.46	1.480	1.990	17.60	2.00	-0.27	0.657	1.475	0.0870	0.0997
7.18	1.615	2.212	15.55	1.93	-0.22	0.731	1.640	0.0920	0.1074
5.02	1.140	1.546	22.45	0.51	-0.46	0.511	1.146	0.0704	0.0783
4.69	0.916	1.445	20.67	-0.48	-0.45	0.477	1.071	0.0553	0.0623
7.83	1.708	2.430	13.62	1.54	-0.22	0.803	1.802	0.0934	0.1118

TABLE A-III

Model 4777 L/B=4 (Nominal) B/T = 3.33 (Nominal)

Model Characteristics: L_{pp} = 3 ft; Δ = 20.72 lbs F.W. at 76°F ; W.A. = 2.61 ft²

Scale Ratio = 16.75 for 100,000-lb ship in 59°F S.W.; C_A=0 for prediction of R_{ship}

VM ft/sec	RM lb	RNM $\times 10^{-6}$	CTM $\times 10^{3}$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
TEST 1: LCG = 2.27-in aft amidship (level trim)									
3.97	0.683	1.223	17.14	0.24	-0.35	0.404	0.842	0.0248	0.0290
5.73	2.739	1.765	33.00	5.21	-0.35	0.583	1.215	0.1163	0.1247
7.54	2.955	2.322	20.56	5.73	0.02	0.767	1.599	0.1164	0.1304
9.32	3.433	2.871	15.64	6.28	0.47	0.949	1.976	0.1272	0.1479
4.69	1.402	1.445	25.22	2.25	-0.41	0.477	0.994	0.0566	0.0624
6.46	2.826	1.990	26.79	5.77	-0.11	0.657	1.370	0.1166	0.1271
5.38	2.413	1.657	32.98	4.89	-0.32	0.548	1.141	0.1023	0.1097
5.02	1.902	1.546	29.86	3.75	-0.32	0.511	1.064	0.0793	0.0858
TEST 2: LCG = 4.07-in aft amidship									
3.98	0.794	1.226	19.83	3.67	-0.16	0.405	0.844	0.0301	0.0344
5.73	3.118	1.765	37.57	8.59	0.04	0.583	1.215	0.1345	0.1429
7.54	3.455	2.322	24.04	9.34	0.40	0.767	1.599	0.1405	0.1545
6.46	3.247	1.990	30.78	8.56	0.28	0.657	1.370	0.1369	0.1474
5.38	2.904	1.657	39.69	7.72	-0.02	0.548	1.141	0.1259	0.1334
5.01	2.255	1.543	35.[illegible]6	7.28	-0.30	0.510	1.062	0.0964	0.1029
TEST 3. LCG = 5.87-in aft amidship									
3.97	1.048	1.223	26.31	7.30	0.13	0.404	0.842	0.0424	0.0466
5.73	4.110	1.765	49.52	11.97	0.47	0.583	1.215	0.1824	0.1908
6.44	4.298	1.984	41.00	12.70	0.80	0.655	1.365	0.1877	0.1961
5.38	3.792	1.657	51.83	11.51	0.41	0.548	1.141	0.1688	0.1762
5.01	2.876	1.543	45.33	10.50	0.36	0.510	1.062	0.1263	0.1328
4.68	2.225	1.441	40.19	9.56	0.29	0.476	0.992	0.0963	0.1021
TEST 4: LCG = 0.47-in aft amidship									
3.93	0.691	1.226	17.26	-2.70	-0.47	0.405	0.844	0.0251	0.0294
5.70	2.646	1.756	32.22	2.43	-0.56	0.580	1.208	0.1119	0.1202
7.54	3.017	2.322	20.99	2.70	-0.29	0.767	1.599	0.1194	0.1334
5.01	1.974	1.543	29.54	0.40	-0.59	0.510	1.062	0.0780	0.0845
5.37	2.357	1.654	32.33	1.77	-0.59	0.547	1.138	0.0996	0.1070
6.44	2.809	1.984	26.79	2.31	-0.37	0.655	1.365	0.1159	0.1263

TABLE A-IV

Model 4780 L/B=5 (Nominal) B/T=5.00 (Nominal)

Model Characteristics: L_{pp} = 3 ft ; Δ = 7.35 lbs F.W. at 76°F ; W.A. = 1.71 ft²

Scale Ratio = 23.65 for 100,000-lb ship in 59°F S.W.;C_A=0 for prediction of R_{ship}

TEST 5: LCG = 1.98-in aft amidship (level trim)

VM ft/sec	RM lb	REM $\times 10^{-6}$	CTM $\times 10^3$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
4.32	0.365	1.331	11.91	1.13	-0.24	0.440	1.089	0.0321	0.0408
3.25	0.147	1.001	8.40	0.11	-0.13	0.331	0.819	0.0095	0.0145
5.74	0.671	1.768	12.30	2.88	-0.14	0.584	1.446	0.0618	0.0763
5.03	0.562	1.549	13.41	2.27	-0.21	0.512	1.267	0.0533	0.0646
6.46	0.756	1.990	10.94	3.20	-0.05	0.657	1.628	0.0664	0.0844
7.17	0.806	2.208	9.47	3.12	0.09	0.730	1.807	0.0656	0.0875
8.24	0.890	2.538	7.91	3.29	0.12	0.839	2.076	0.0643	0.0927
9.32	1.070	2.871	7.44	3.10	0.19	0.949	2.346	0.0745	0.1103

TEST 6: LCG = 3.78-in aft amidship

VM ft/sec	RM lb	REM $\times 10^{-6}$	CTM $\times 10^3$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
4.32	0.415	1.331	13.43	2.97	-0.11	0.440	1.089	0.0389	0.0474
3.26	0.169	1.004	9.60	1.62	-0.07	0.332	0.821	0.0124	0.0175
5.74	0.713	1.766	13.07	4.49	0.02	0.584	1.446	0.0675	0.0820
5.03	0.570	1.549	13.60	4.00	-0.03	0.512	1.267	0.0544	0.0657
6.46	0.767	1.990	11.10	4.73	0.12	0.657	1.628	0.0679	0.0859
7.17	0.846	2.208	9.94	5.05	0.18	0.730	1.807	0.0710	0.0929
7.89	0.910	2.430	8.83	5.06	0.27	0.803	1.988	0.0713	0.0975
3.97	0.295	1.223	11.30	2.34	-0.12	0.404	1.000	0.0250	0.0323

TEST 7: LCG = 5.58-in aft amidship

VM ft/sec	RM lb	REM $\times 10^{-6}$	CTM $\times 10^3$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
4.32	0.570	1.331	18.44	5.02	0.04	0.440	1.089	0.0500	0.0585
3.26	0.211	1.004	11.99	3.32	0.05	0.332	0.821	0.0181	0.0232
5.74	0.565	1.768	15.65	6.67	0.32	0.584	1.446	0.0862	0.1077
6.46	0.921	1.990	13.33	6.92	0.46	0.657	1.628	0.0866	0.1068
6.46	0.930	1.990	13.46	6.92	0.45	0.657	1.628	0.0910	0.1081
7.17	0.994	2.208	11.67	7.06	0.54	0.730	1.807	0.0911	0.1130
5.03	0.756	1.549	18.09	6.17	0.18	0.512	1.267	0.0799	0.0913
3.97	0.398	1.223	15.25	4.29	0.05	0.404	1.000	0.0391	0.0465

TEST 8: LCG = 0.18-in aft amidship

VM ft/sec	RM lb	REM $\times 10^{-6}$	CTM $\times 10^3$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
4.32	0.343	1.331	11.10	-0.70	-0.36	0.440	1.089	0.0281	0.0376
7.89	0.930	2.430	9.02	1.81	-0.12	0.803	1.988	0.0740	0.1002
5.74	0.634	1.768	11.62	1.24	-0.30	0.584	1.446	0.0562	0.0713
5.02	0.508	1.546	12.17	0.84	-0.35	0.511	1.265	0.0460	0.0573
3.25	0.124	1.001	7.09	-1.46	-0.23	0.331	0.819	0.0064	0.0114
3.97	0.236	1.223	9.04	-1.30	-0.30	0.404	1.000	0.0170	0.0243
7.17	0.826	2.208	9.70	1.83	-0.20	0.730	1.807	0.0683	0.0902

TABLE A-V

Model 4777 L/B=4 (Nominal) B/T = 5.00 (Nominal)

Model Characteristics: L_{pp} = 3 ft; Δ = 11.48 lbs F.W. at 76°F ; W.A. = 2.14 ft²

Scale Ratio = 20.39 for 100 000-lb ship in 59°F S.W.; C_A=0 for prediction of R_{ship}

TEST 5: LCG = 1.98-in aft amidship (level trim)

VM ft/sec	RM lb	REM $\times 10^{-6}$	CTM $\times 10^{3}$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
3.98	0.382	1.226	11.64	0.43	-0.25	0.405	0.931	0.0211	0.0272
5.72	1.121	1.762	16.53	3.70	-0.16	0.582	1.338	0.0742	0.0861
7.54	1.320	2.322	11.20	4.18	0.06	0.767	1.764	0.0763	0.0961
6.46	1.213	1.990	14.02	4.12	-0.03	0.657	1.511	0.0764	0.0913
4.69	0.772	1.445	16.93	2.40	-0.23	0.477	1.097	0.0509	0.0591
5.02	0.890	1.546	17.04	3.04	-0.21	0.511	1.174	0.0590	0.0683
6.11	1.160	1.882	14.99	4.10	-0.07	0.622	1.429	0.0746	0.0880
4.33	0.551	1.334	14.18	1.42	-0.24	0.441	1.013	0.0338	0.0409

TEST 6: LCG = 3.78-in aft amidship

VM ft/sec	RM lb	REM $\times 10^{-6}$	CTM $\times 10^{3}$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
3.98	0.419	1.226	12.76	2.50	-0.10	0.405	0.931	0.0244	0.0304
5.73	1.219	1.765	17.91	5.71	0.08	0.583	1.340	0.0826	0.0946
7.54	1.421	2.322	12.05	6.28	0.40	0.767	1.764	0.0850	0.1049
5.01	1.028	1.543	19.76	5.21	0.02	0.510	1.172	0.0711	0.0804
4.69	0.893	1.445	19.59	4.61	-0.02	0.477	1.097	0.0614	0.0696
4.32	0.624	1.331	16.13	3.34	-0.05	0.440	1.011	0.0403	0.0473

TEST 7: LCG = 5.58-in aft amidship

VM ft/sec	RM lb	REM $\times 10^{-6}$	CTM $\times 10^{3}$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
3.97	0.587	1.223	17.97	5.16	0.16	0.404	0.929	0.0390	0.0451
5.74	1.492	1.768	21.85	8.25	0.47	0.584	1.343	0.1063	0.1183
7.54	1.797	2.322	15.25	9.20	0.89	0.767	1.764	0.1178	0.1377
4.97	1.278	1.531	24.96	7.59	0.30	0.506	1.163	0.0931	0.1023
4.67	1.135	1.438	25.11	7.02	0.25	0.475	1.092	0.0826	0.0908
4.33	0.840	1.334	21.62	6.06	0.21	0.441	1.013	0.0590	0.0661

TEST 8: LCG = 0.18-in aft amidship

VM ft/sec	RM lb	REM $\times 10^{-6}$	CTM $\times 10^{3}$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
3.97	0.376	1.223	11.51	-1.83	-0.41	0.404	0.929	0.0207	0.0267
5.72	1.146	1.762	16.90	1.70	-0.43	0.582	1.338	0.0764	0.0883
7.53	1.416	2.319	12.05	1.94	-0.12	0.766	1.762	0.0847	0.1045
4.99	0.865	1.537	16.76	0.84	-0.41	0.508	1.167	0.0570	0.0663
5.38	1.020	1.657	17.00	1.35	-0.42	0.548	1.259	0.0679	0.0785
4.67	0.716	1.432	15.94	0.09	-0.50	0.475	1.092	0.0451	0.0543
6.46	1.270	1.990	14.68	1.75	-0.25	0.657	1.511	0.0814	0.0963

TABLE A-VI

Model 4779 L/B = 3 (Nominal) B/T = 5.00 (Nominal)

Model Characteristics: L_{pp} = 3 ft ; Δ = 20.41 lbs F.W. at 76°F ; W.A. 2.84 ft²

Scale Ratio = 16.83 for 100,000-lb ship in 59°F S.W.;C_A=0 for prediction of R_{ship}

VM ft/sec	RM lb	REM $\times10^{-6}$	CTM $\times10^{3}$	TRIM deg	HEAVE in	FNL	FND	RROD	RSOD
TEST 1. LCG = 1.98-in aft amidship (level trim)									
3.97	0.697	1.223	16.08	0.13	-0.42	0.404	0.844	0.0251	0.0298
5.73	2.761	1.765	30.79	5.96	-0.37	0.583	1.218	0.1187	0.1279
7.53	2.843	2.319	18.23	6.17	0.09	0.766	1.600	0.1104	0.1258
8.24	3.143	2.538	16.83	6.48	0.21	0.839	1.751	0.1200	0.1382
6.81	2.871	2.098	22.51	6.23	-0.03	0.693	1.447	0.1166	0.1294
5.00	2.017	1.540	29.33	3.96	-0.43	0.509	1.063	0.0851	0.0923
6.46	2.882	1.990	25.11	6.42	-0.07	0.657	1.373	0.1193	0.1309
6.10	2.806	1.879	27.42	6.34	-0.14	0.621	1.297	0.1178	0.1282
4.69	1.483	1.445	24.51	2.59	-0.37	0.477	0.997	0.0504	0.0368
TEST 2: LCG = 3.78-in aft amidships									
7.53	3.146	2.319	20.17	8.83	0.38	0.766	1.600	0.1253	0.1497
6.81	3.145	2.098	24.66	8.84	0.21	0.693	1.447	0.1301	0.1429
5.39	2.778	1.660	34.95	8.09	-0.12	0.549	1.146	0.1224	0.1286
4.69	1.607	1.445	26.55	5.57	-0.21	0.477	0.997	0.0665	0.0729
6.17	3.039	1.900	29.02	8.41	-0.06	0.628	1.311	0.1288	0.1394
3.97	0.742	1.223	17.12	4.78	0.00	0.404	0.844	0.0273	0.0320
TEST 3: LCG = 5.58-in aft amidships									
3.97	0.986	1.223	22.74	5.55	-0.10	0.404	0.844	0.0383	0.0440
7.53	4.469	2.319	28.66	12.27	0.57	0.766	1.600	0.1901	0.2055
5.38	3.542	1.657	44.49	10.95	0.12	0.548	1.143	0.1578	0.1661
4.68	2.112	1.441	35.05	8.00	0.57	0.476	0.995	0.0913	0.0976
6.81	4.160	2.098	32.61	11.69	0.46	0.693	1.447	0.1797	0.1925
6.09	3.898	1.876	38.21	11.00	0.50	0.620	1.294	0.1713	0.1817
TEST 4: LCG = 0.18-in aft amidships									
3.97	0.719	1.223	16.59	-2.47	-0.73	0.404	0.844	0.0262	0.0309
5.73	2.888	1.765	31.98	3.77	-0.77	0.583	1.218	0.1239	0.1332
7.54	3.270	2.322	20.91	3.	-0.53	0.767	1.603	0.1313	0.1467
6.81	3.090	2.098	24.22	3.29	-0.59	0.693	1.447	0.1273	0.1401
4.68	1.629	1.441	27.04	-0.02	-0.75	0.476	0.993	0.0678	0.0740
4.32	1.098	1.331	21.36	-1.36	-0.82	0.440	0.918	0.0433	0.0488
5.33	2.691	1.507	[illegible]	3.72	[illegible]	0.540	1.143	0.1162	0.1244

APPENDIX B

INFLUENCE OF LCG VARIATIONS ON PRE-PLANING RESISTANCE

Small craft operations frequently entail substantial variations of longitudinal weight distributions which, depending upon speed, are known to produce important variations of resistance. Test results for nine models, in some cases with more than one displacement, with several different LCG positions have been analyzed to derive approximate equations for estimating the change in R_T/Δ for a given change in LCG position from a nominal standard. These results can be used, together with Eqs. (6) to estimate resistance of a proposed design for its "standard" LCG condition and for variations from this condition. It should be noted that the equations are intended for use in predicting influence of variations in LCG position for a given hull form and probab , are not suitable for predicting the optimum LCG position in the course of hull lines development for a new design.

The resistance data for Series 62 models (hard chines and full waterline endings) which were used as part of the data for deriving Eq. (6) correspond to the LCG position 4 percent of L_{pp} aft of the centroid of the projected horizontal area below the chines. This "standard" condition, which was selected somewhat arbitrarily, is close to the optimum for minimum R_T/Δ, but the exact optimum LCG varies, depending on $F_{n\nabla}$, displacement, L_{WL}/B_x, and other factors. For Series 63 models (round bilge and somewhat finer bow waterline endings) the data used in the development of Eq. (6) were taken from Beys[11] report all of which correspond to level keel conditions. Test results reported in Appendix A indicate that this condition is a fairly good approximation of the optimum LCG position for the speeds, models and displacements covered. Figure 17 shows the range of variation of $\overline{LCG}/L_{pp}$ (measured from ⊕) for Series 62 and Series 63 models, as well as all of the other Series models.

In applying the following approximations for the variation of resistance with variation of LCG, it is necessary to e[illegible]ate the specific LCG position for which Eq. (6) is assumed to apply, and then use the approximating equations given below for variations from that "st[illegible]ard" LCG.

For most ad hoc hull forms, this may be simply assumed to lie at the middle of the range of values exhibited in Figure 17, namely $\overline{LCG}/L_{pp}$ = 4.5 percent aft of ⊠, and this may be assumed to correspond to the optimum position. If, however, the designer, by virtue of his experience and knowledge of test results for a hull form sufficiently similar to the ad hoc form, considers that the "standard" LCG position corresponds to some other value and is not exactly optimum, he may develop alternative procedures for applying the corrections for variations in LCG position. For instance, if the ad hoc form is similar to a Series 62 model, with $L/B \sim 3$, it may be better to assume Eq. (6) applies for the "standard" LCG position about 5-3/4 percent aft of ⊠ and that it is not exactly optimum, and use the results described below to estimate the variations in R_T/Δ for variations in $\overline{LCG}/L_{pp}$ from -.0575.

Data (R_T/Δ for 100,000-lb. ship in 59°F S.W., C_A = 0.0) for models of Series 62 (Ref. 3) and Series 63 (Appendix A of this report) have been tabulated from faired curves for the conditions of displacements and LCG position available from these tests for values of $F_{n\nabla}$ = 1.1, 1.3, 1.5, 1.7 and 1.9. There are at least 4, and sometimes 5, LCG positions for each of 20 model-displacement conditions. Least-squares curve fits of these data according to the equation

$$\frac{R_T}{\Delta} - \left(\frac{R_T}{\Delta}\right)_{standard} = \alpha + \beta\delta + \gamma\delta^2 \qquad \text{(B-1)}$$

where

$\left(\frac{R_T}{\Delta}\right)_{standard}$ is the value of $\left(\frac{R_T}{\Delta}\right)$ corresponding to the "standard" LCG position

and

$$\delta = 100 \times \frac{(\overline{LCG})_{standard} - \overline{LCG}}{L_{pp}}$$ (δ is positive if the LCG is aft of the standard LCG)

for each of the 14 or more model and displacement conditions at each $F_{n\nabla}$ (some model variations did not extend to the highest $F_{n\nabla}$'s, due to danger of swamping the model during start or stop of test, or for other reasons).

The application of the form of Eq. (B-1) was suggested by carpet-plotting of resistance data, as illustrated in Figure B-1, for Series 62 Model 4666, with $L/\nabla^{1/3} = 5.082$. The iso-$F_{n\nabla}$ curves are roughly parabolic for this case and others as well. It may be noted that the optimum LCG position for this case is about 8% aft of the centroid of A_p (the area of the chine projection on a horizontal plane), and not at the 4% value used as the nominal standard LCG position. This is true over most of the speed range except at the extremes, $F_{n\nabla} = 1.0$ and $F_{n\nabla} = 2.0$. The optimum LCG depends, in general, on the displacement and other hull form coefficients in addition to the speed.

The α, β and γ coefficients have been analyzed to determine their dependence on hull form coefficients $L/\nabla^{1/3}$ and i_e for each $F_{n\nabla}$. The mean value of α is negligibly small for all $F_{n\nabla}$ which gives $R_T/\Delta = R_T/\Delta_{\text{standard}}$ for LCG = $\text{LCG}_{\text{standard}}$.

The β and γ coefficients dependence upon hull form characteristics have been approximated by the following equations:

$$\beta = \beta_1 + \beta_2 X + \beta_3 U + \beta_4 XU + \beta_5 X^2 + \beta_6 U^2 + \beta_7 UX^2 + \beta_8 XU^2 \qquad \text{(B-2)}$$

$$\gamma = \gamma_1 + \gamma_2 X + \gamma_3 U + \gamma_4 XU + \gamma_5 X^2 + \gamma_6 U^2 + \gamma_7 UX^2 + \gamma_8 XU^2 \qquad \text{(B-3)}$$

where $X = \nabla^{1/3}/\text{LWL}$ and $U = \sqrt{2i_e}$, as for Eq. (6). Values for the β_i's and γ_i's for five Froude numbers, $F_{n\nabla} = 1.1$, 1.3, 1.5, 1.7 and 1.9, are given in Tables B-I and B-II. The β_i coefficients have been derived using the data for Series 62 models only. For Series 63, the values of β are rather small and may be neglected.

For application to ad hoc forms, it is suggested that the coefficient β be omitted; that is, assume that the "standard" LCG position corresponds to the optimum. This approximation is expected to be acceptable for most cases for $F_{n\nabla}$ between 1.0 and 2.0, but does not hold for Series 62 models, especially for the shortest model of that series.

Changes in resistance due to changes in LCG position should be considered to be influences on residuary resistance and, hence, not dependent on craft size (Reynolds number).

The application of these equations to a particular hull form is illustrated in Figure 21 for Series 62 model 4665, test 3, which has $L_{WL}/\nabla^{1/3} = 3.6$ and the assumed "standard" $\delta = LCG/L_{pp} = -0.65$.

TABLE B-1

COEFFICIENTS FOR ESTIMATING VARIATION IN RESISTANCE FOR VARIATION IN LCG

$$\frac{R_T}{\Delta} - \left(\frac{R_T}{\Delta}\right)_{standard} = \beta\delta + \gamma\delta^2$$

β Coefficients (for Series 62 only)

$X = \nabla^{1/3}/L$ $\quad U = \sqrt{2i_e}$

Coeff	Multiplies	$F_{n\nabla}$ = 1.1	1.3	1.5	1.7	1.9
β_1	i	0.06266	0.11387	0.26617	-0.03665	-0.17794
β_2	X	-1.44723	-2.89942	-2.14275	-	-0.22876
β_3	U	-0.C.717	-0.01237	-0.06276	-	0.05139
β_4	XU	0.28849	0.57726	0.48763	0.22880	-
β_5	X^2	-	-	-	-7.63330	-
β_6	U^2	-	-	0.00412	-	-0.00368
β_7	UX^2	0.02496	0.09913	0.23579	0.73419	-
β_8	XU^2	-0.01443	-0.03025	-0.03469	-0.02065	0.00374

TABLE B-11

COEFFICIENTS FOR ESTIMATING VARIATION IN RESISTANCE
FOR VARIATION IN LCG

$$\frac{R_T}{\Delta} - \left(\frac{R_T}{\Delta}\right)_{standard} = \beta\delta + \gamma\delta^2$$

γ Coefficients

$X = \nabla^{1/3}/L \qquad U = \sqrt{2i_e}$

Coeff	Multiplies	$F_{n\nabla}$ = 1.1	1.3	1.5	1.7	1.9
γ_1	1	-0.01147	-0.02147	-	0.02789	0.05502
γ_2	X	-	-	-0.12525	-0.32487	-0.15222
γ_3	U	0.00448	0.00814	0.00337	-0.00308	-0.01430
γ_4	XU	-0.02294	-0.03942	-0.01197	0.03516	0.04318
γ_5	X^2	0.56067	0.98997	0.95193	0.93321	-
γ_6	U^2	-0.00035	-0.00064	-0.00037	-	0.00096
γ_7	UX^2	-0.06164	-0.11365	-0.10312	-0.09722	0.01656
γ_8	XU^2	0.00250	0.00448	0.00278	-	-0.00347

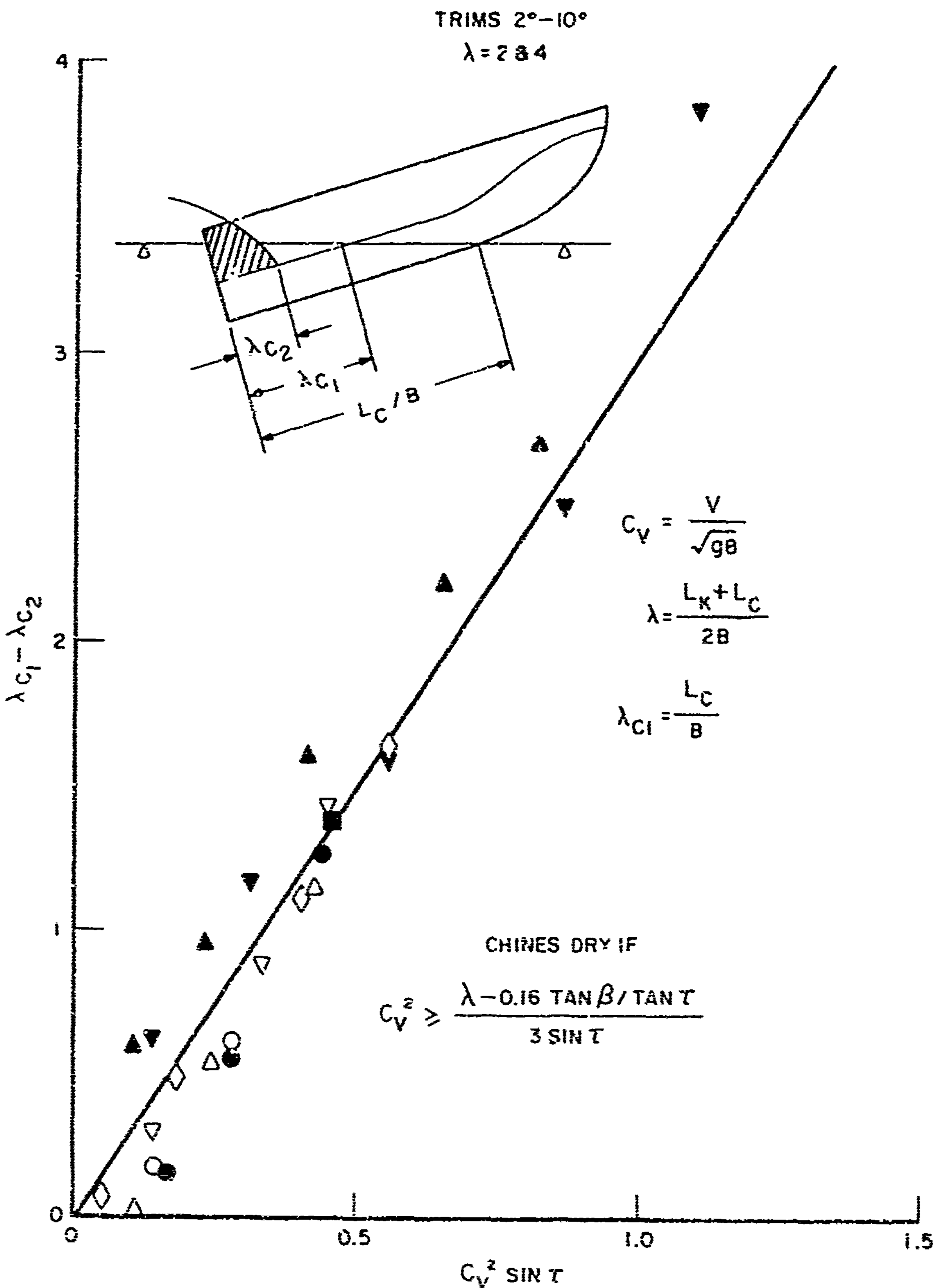

FIG. 1. EXTENT OF CHINE WETTING FOR PRISMATIC DEADRISE HULLS

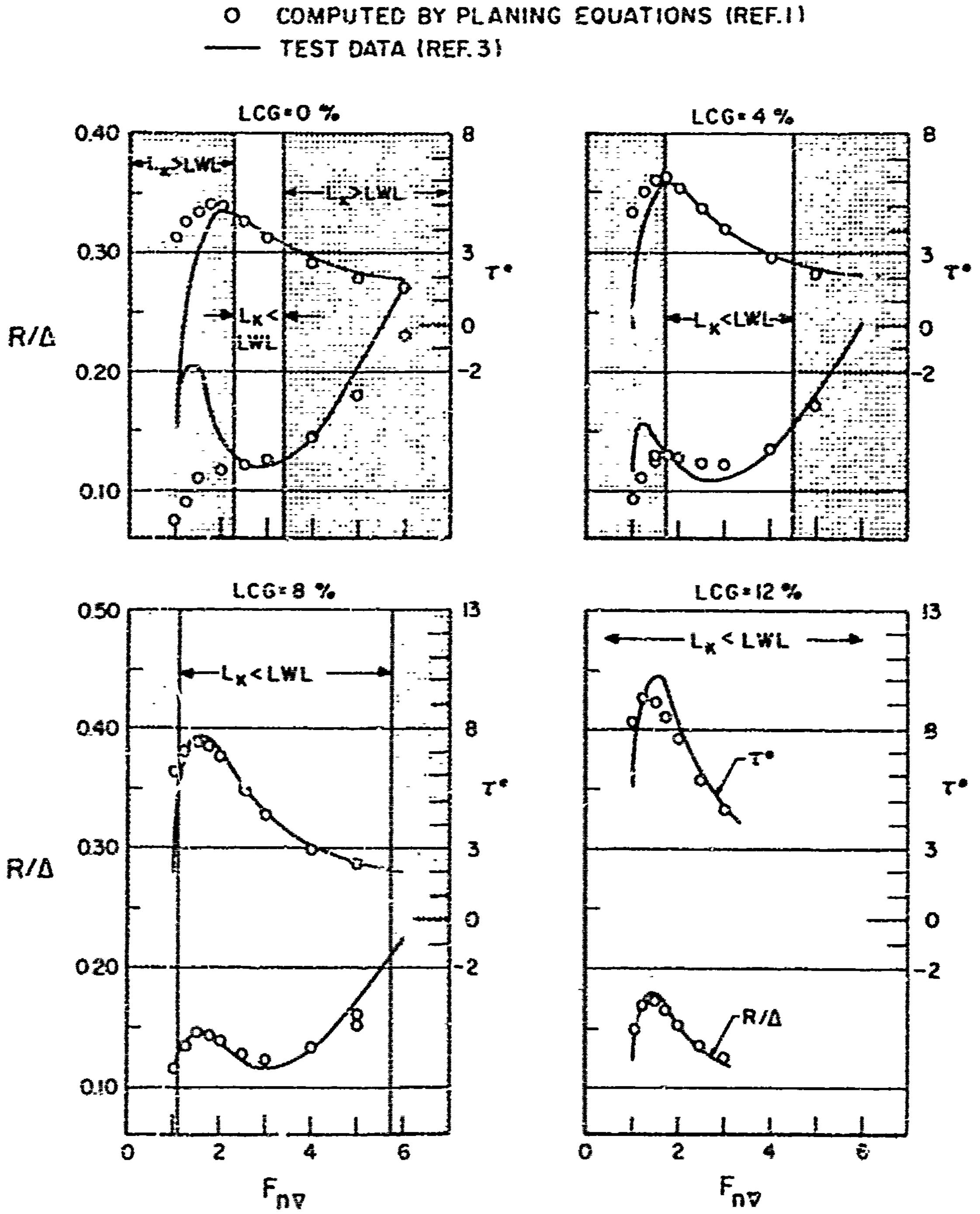

FIG. 2. RESISTANCE AND TRIM VS F_{∇} SERIES 62, L/B = 7.0, $A_p/\nabla^{2/3}$ = 7.0, Δ = 100,000 LBS

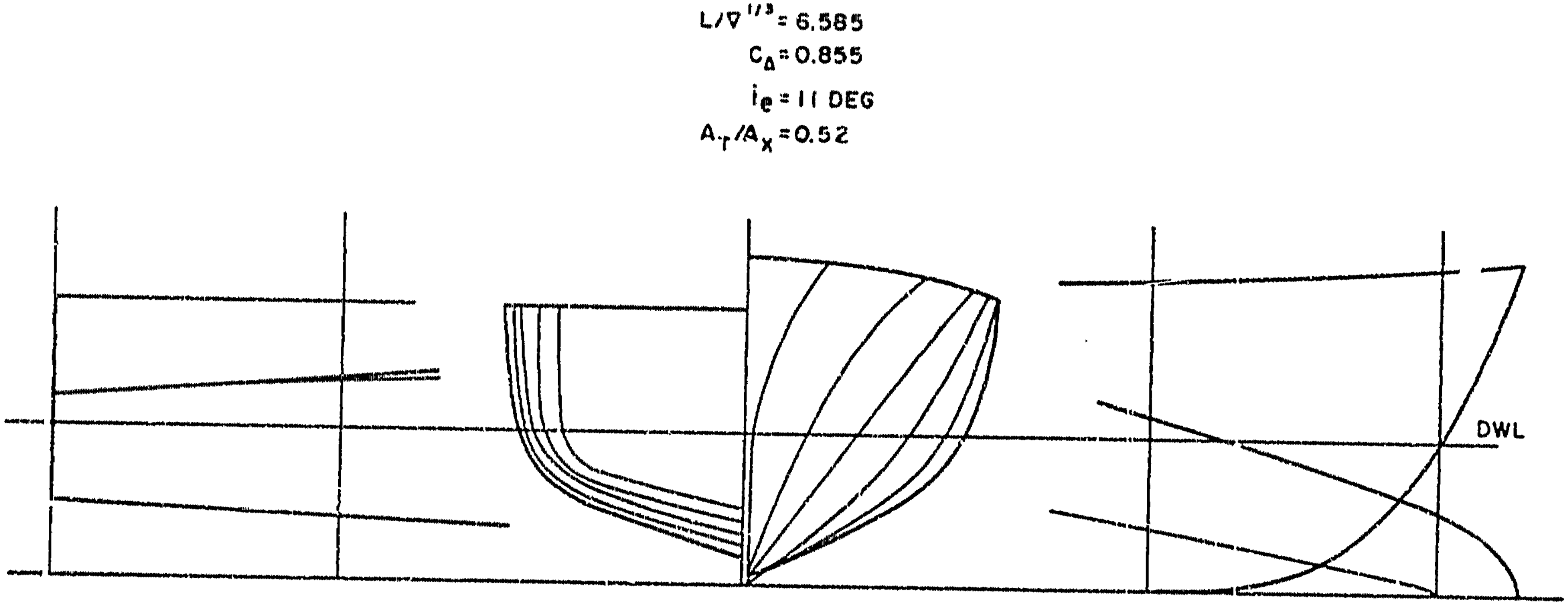

FIG. 3. HULL FORM FOR NPL SERIES (MARWOOD AND BAILEY, REF 4)

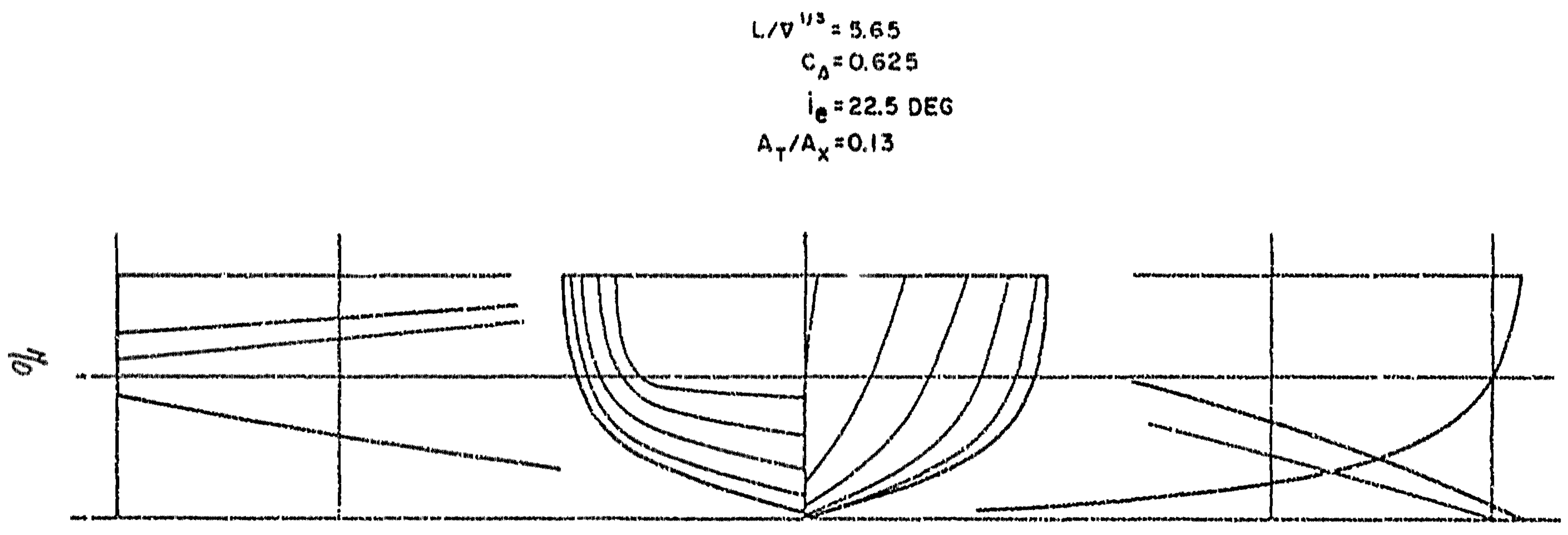

FIG. 4. HULL FORM FOR NORDSTROM SERIES (REF 7)

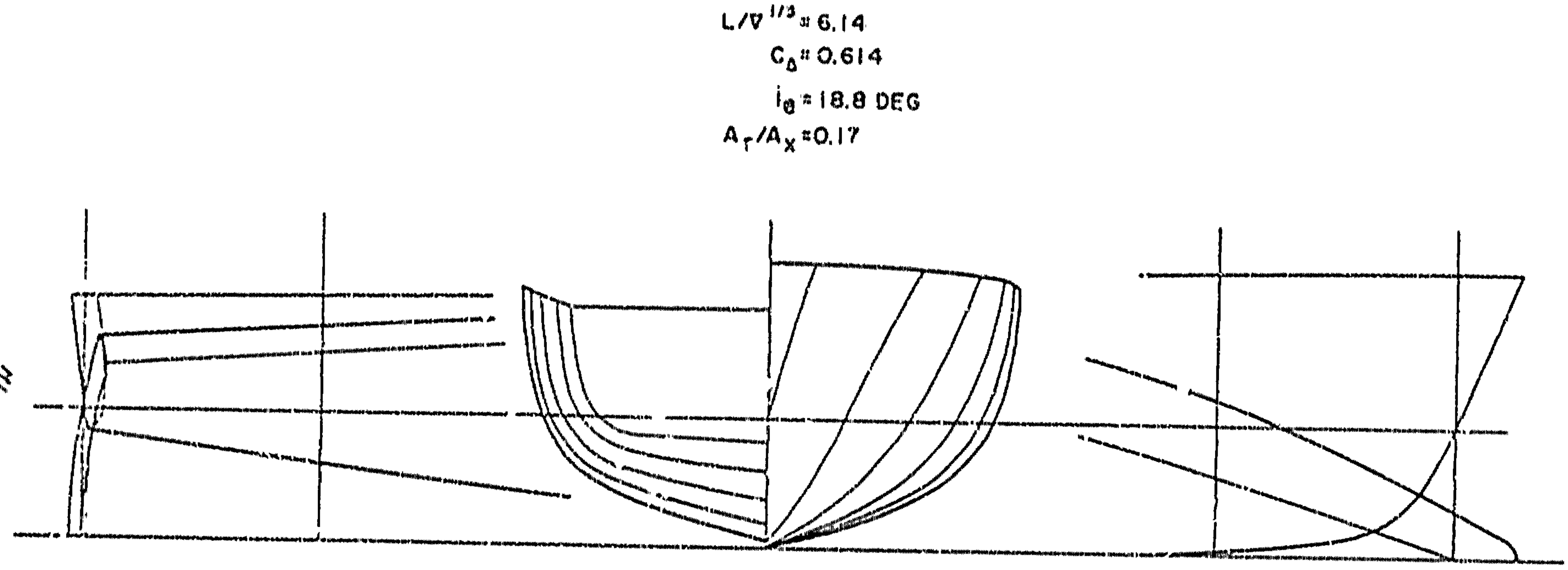

FIG. 5. HULL FORM FOR DEGROOT SERIES (REF 8)

$L/\nabla^{1/3} = 7.0$

$C_\Delta = 0.705$

$i_e = 10.8$ DEG

$A_T/A_X = 0.42$

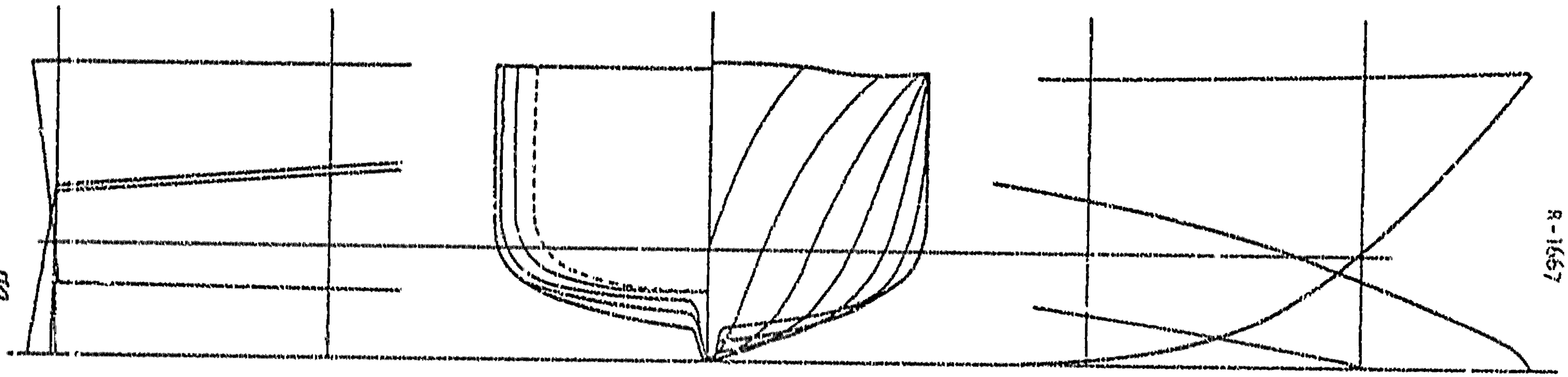

FIG. 6. HULL FORM FOR SSPA SERIES (LINDGREN AND WILLIAMS, REF 9)

$L/\nabla^{1/3} = 8.50$

$C_B = 0.655$

$i_e = 6.7$ DEG

$A_T/A_X = 0.41$

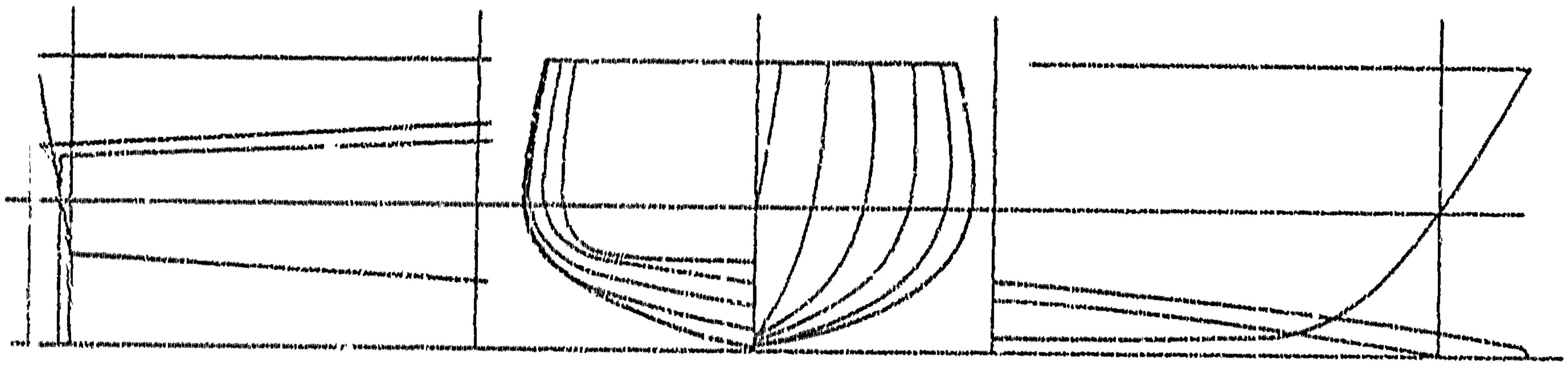

FIG. 7 HULL FORM FOR SERIES 64 (YEH, REF 10)

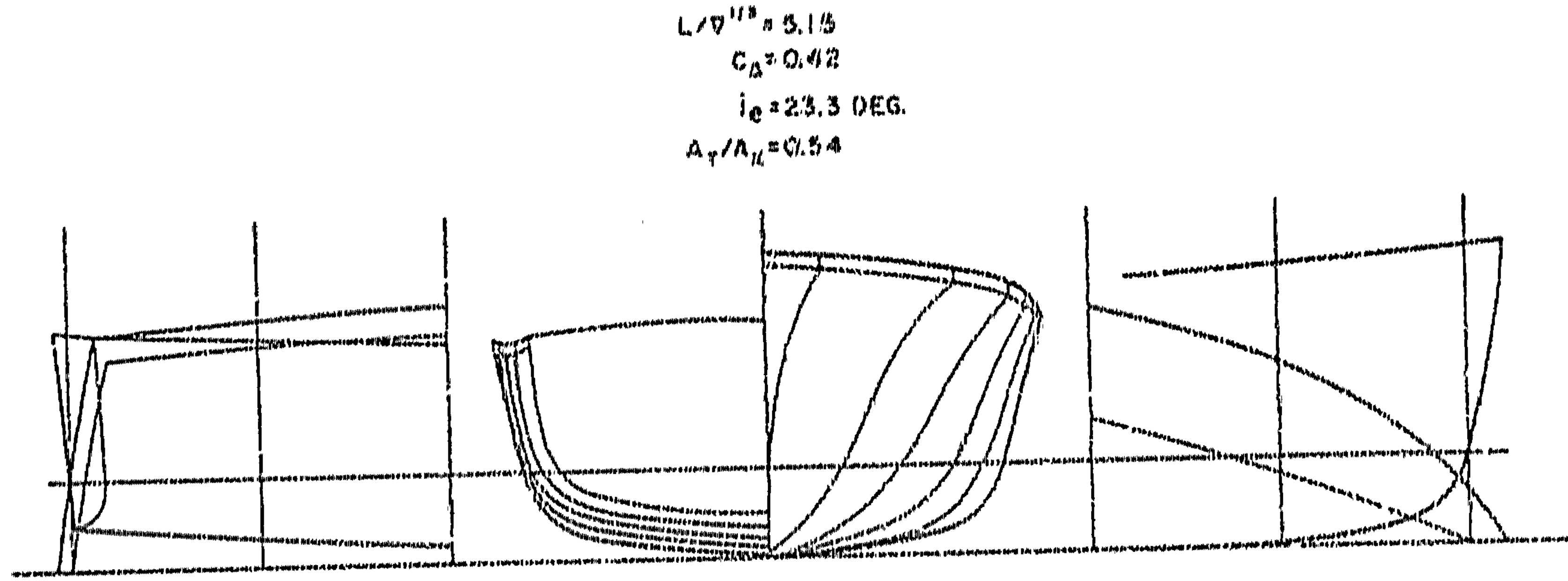

FIG. 8. HULL FORM FOR SERIES 63 (BEYS, REF 11)

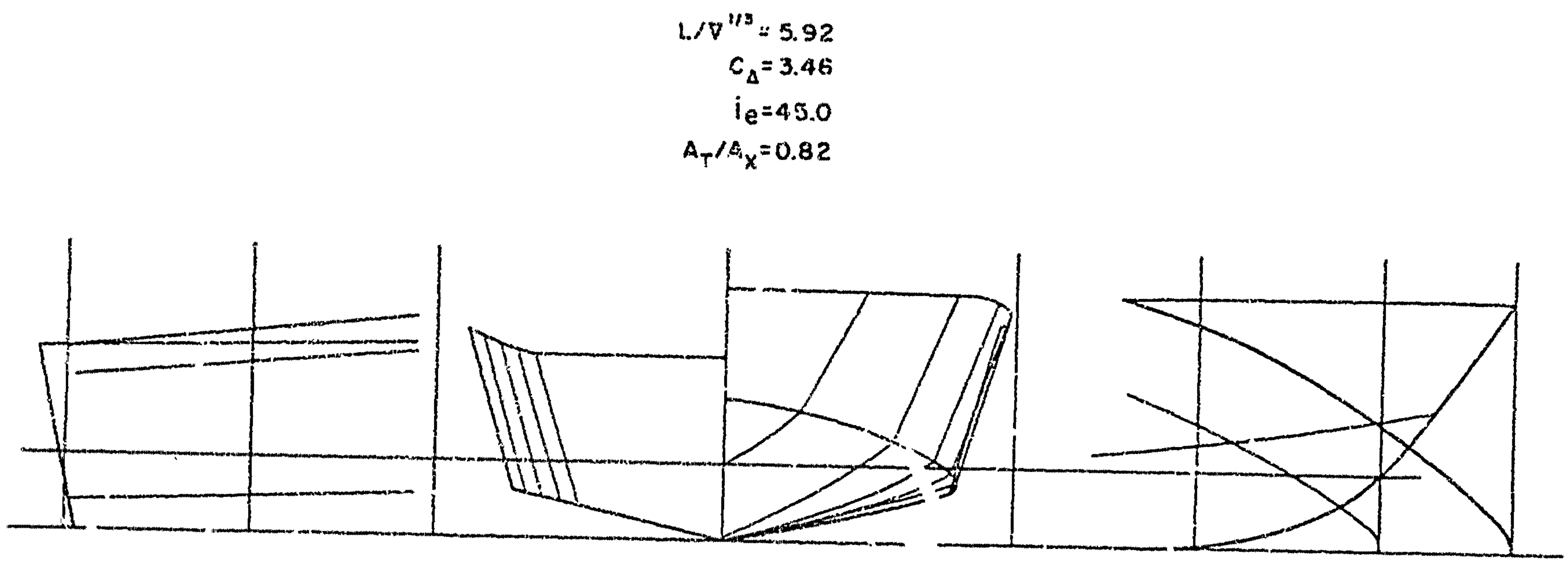

FIG. 9. HULL FORM FOR SERIES 62 (CLEMENT AND BLOUNT, REF 3)

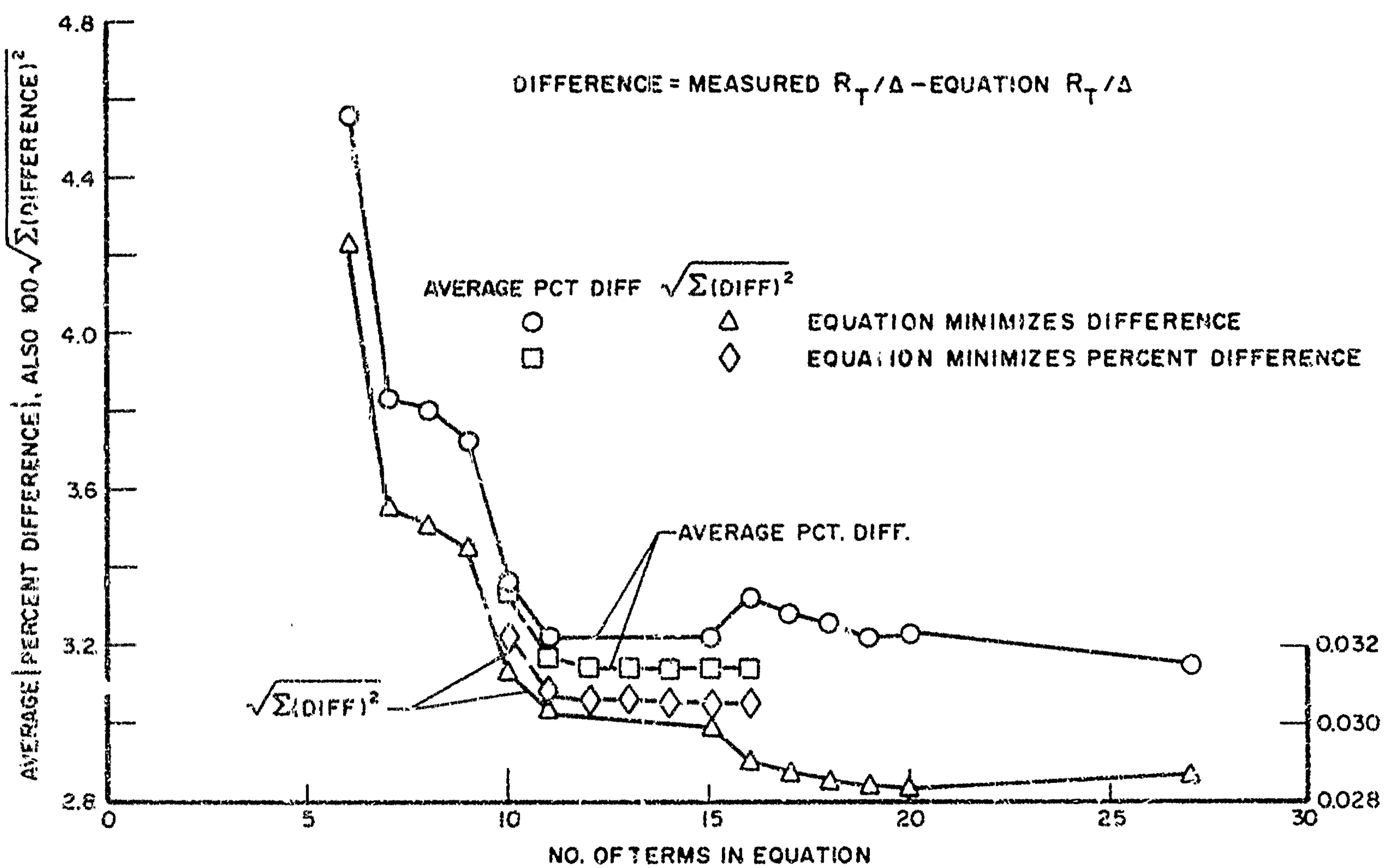

FIG. 10. INFLUENCE OF NUMBER OF TERMS IN RESISTANCE EQUATION ON GOODNESS OF FIT FOR $F_{n\nabla}$ = 1.5 (118 DATA POINTS)

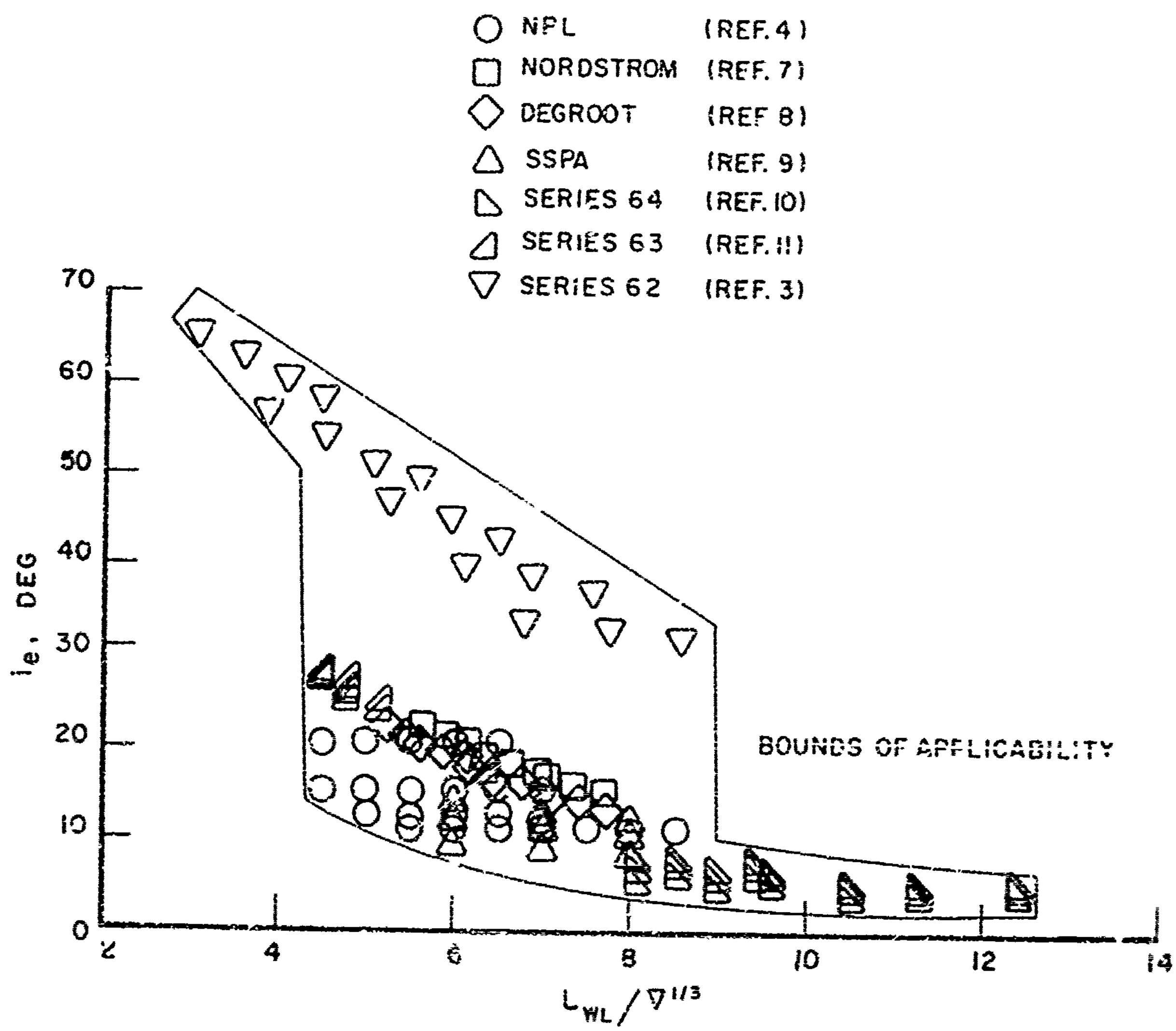

FIG. 11. RANGE OF VARIATION OF i_e AS A FUNCTION OF $L_{WL}/\nabla^{1/3}$ FOR MODELS USED IN DEVELOPING RESISTANCE-ESTIMATING EQUATION

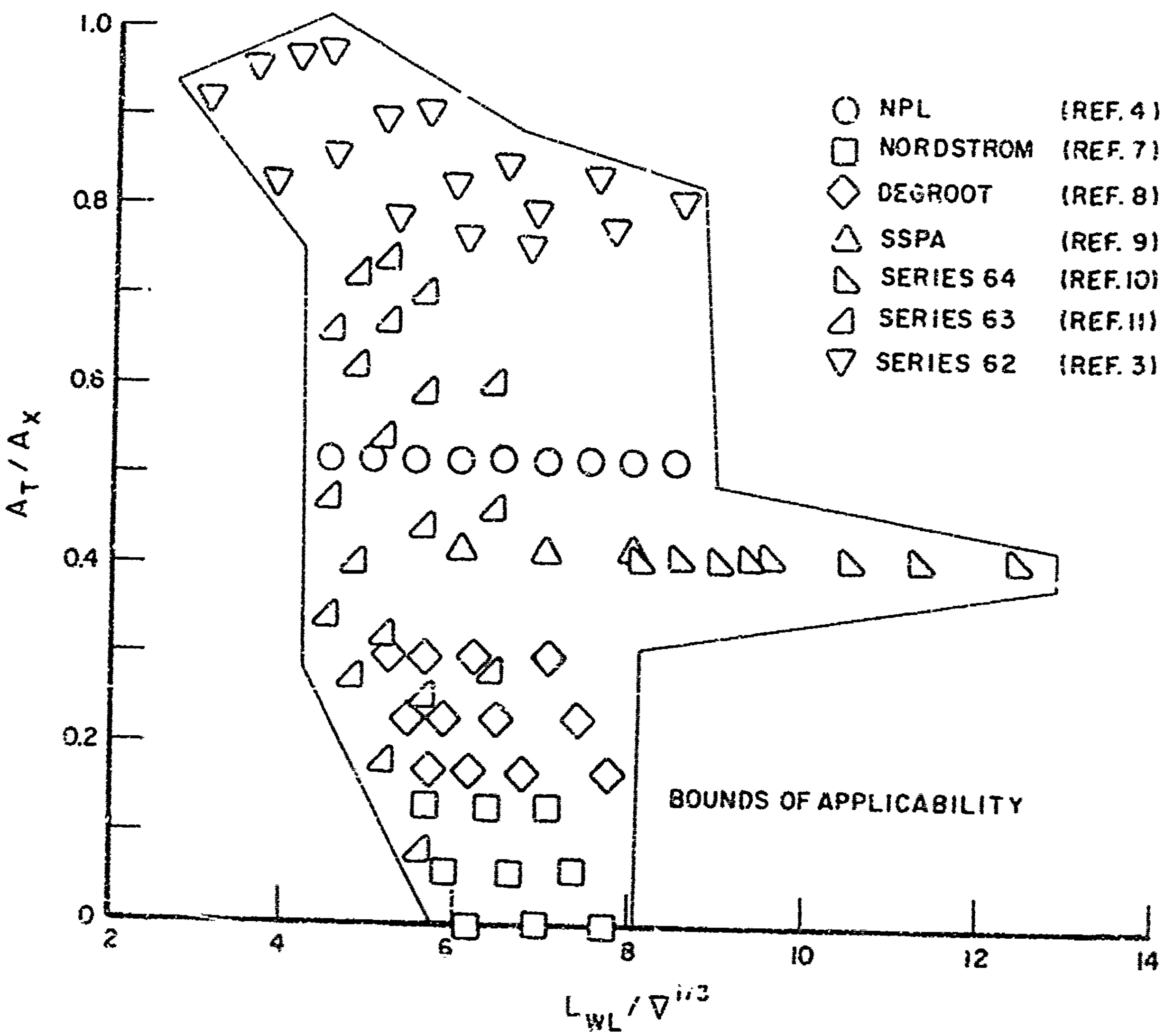

FIG. 12. RANGE OF VARIATION OF A_T/A_X AS A FUNCTION OF $L_{WL}/\nabla^{1/3}$ FOR MODELS USED IN DEVELOPING RESISTANCE-ESTIMATING EQUATION

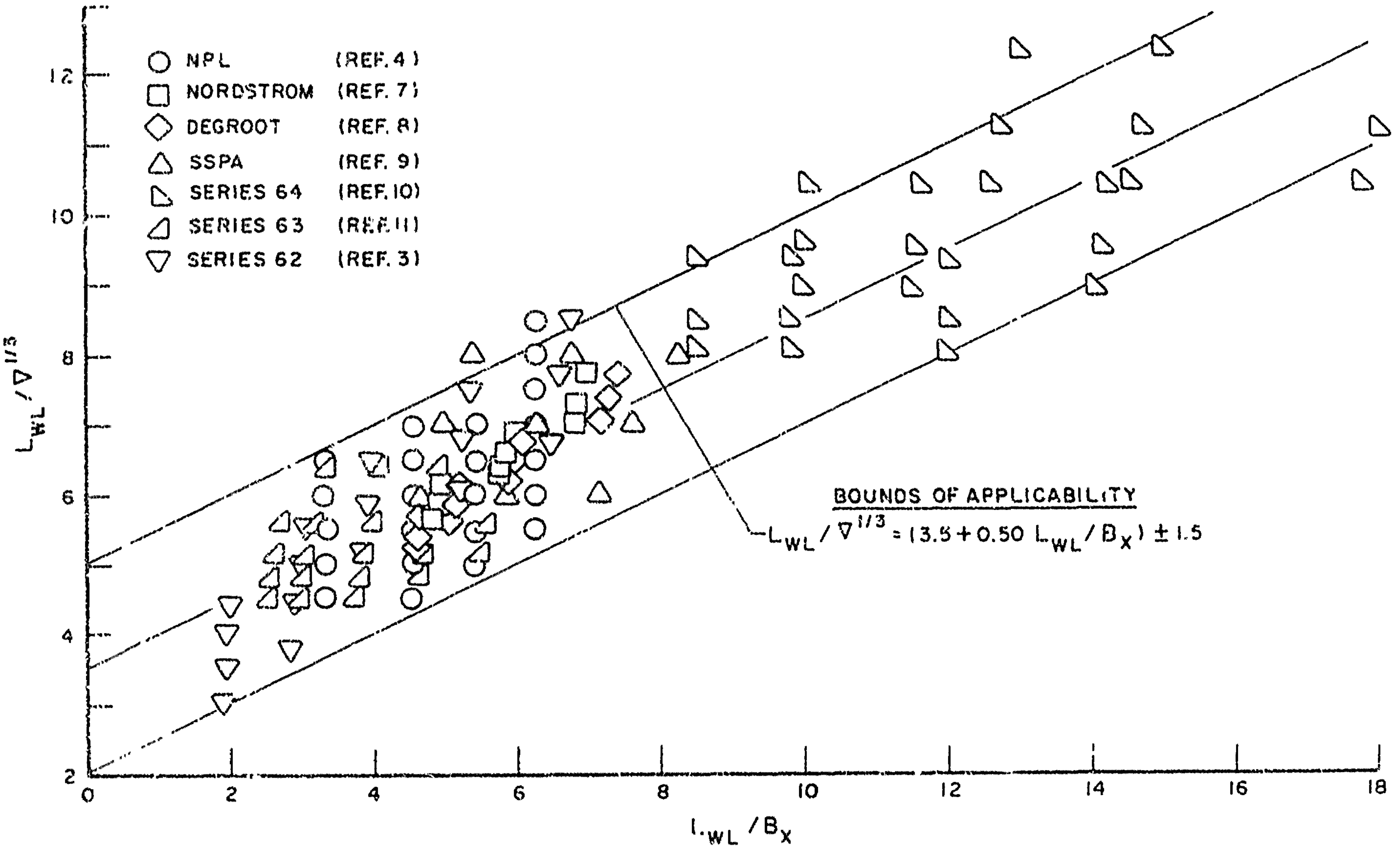

FIG. 13. RANGE OF VARIATION OF L_{WL}/B AS A FUNCTION OF $L_{WL}/\nabla^{1/3}$ FOR MODELS USED IN DEVELOPING RESISTANCE-- ESTIMATING EQUATION

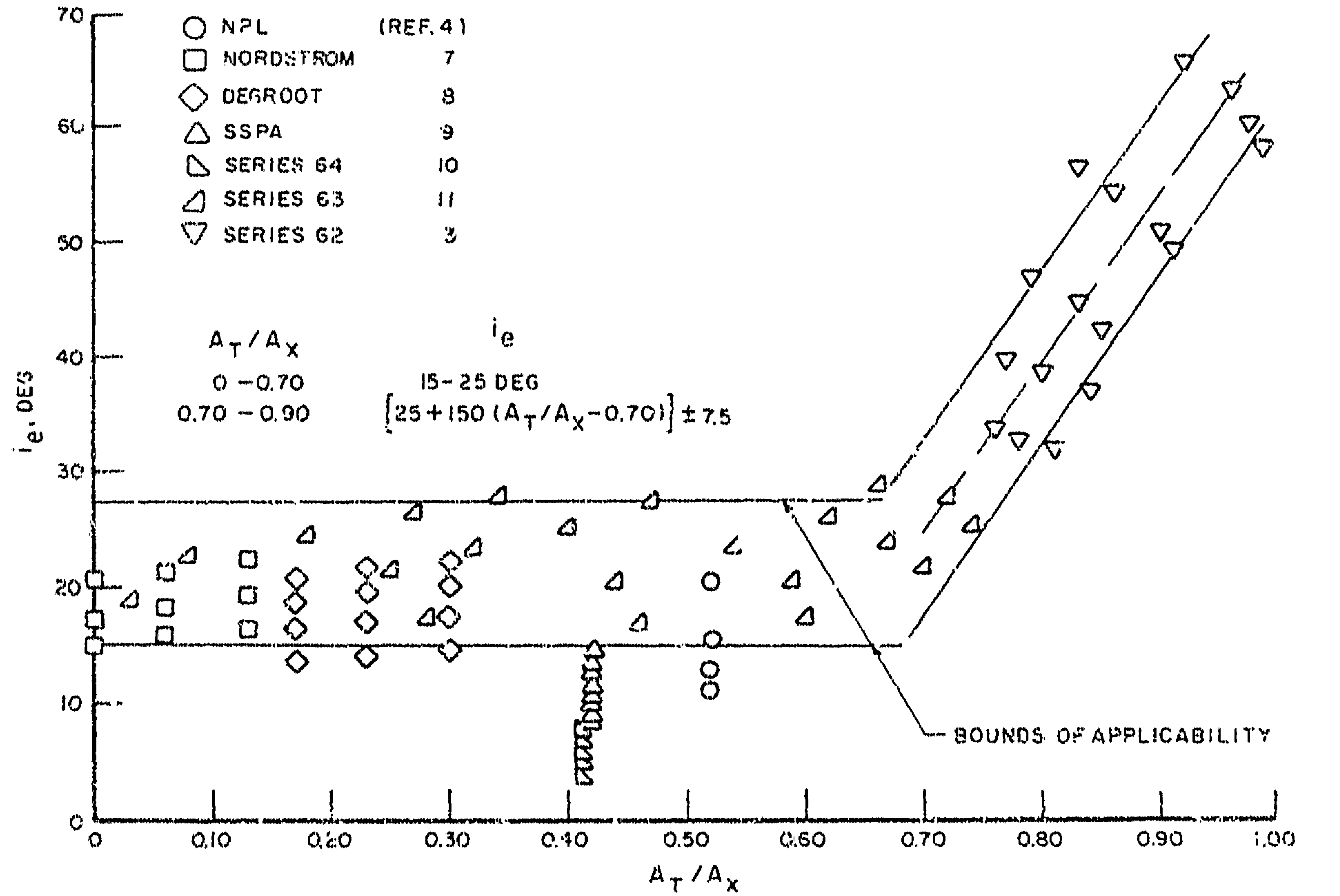

FIG. 14. RANGE OF VARIATION OF i_e AS A FUNCTION OF A_T/A_X FOR MODELS USED IN DEVELOPING RESISTANCE–ESTIMATING EQUATION

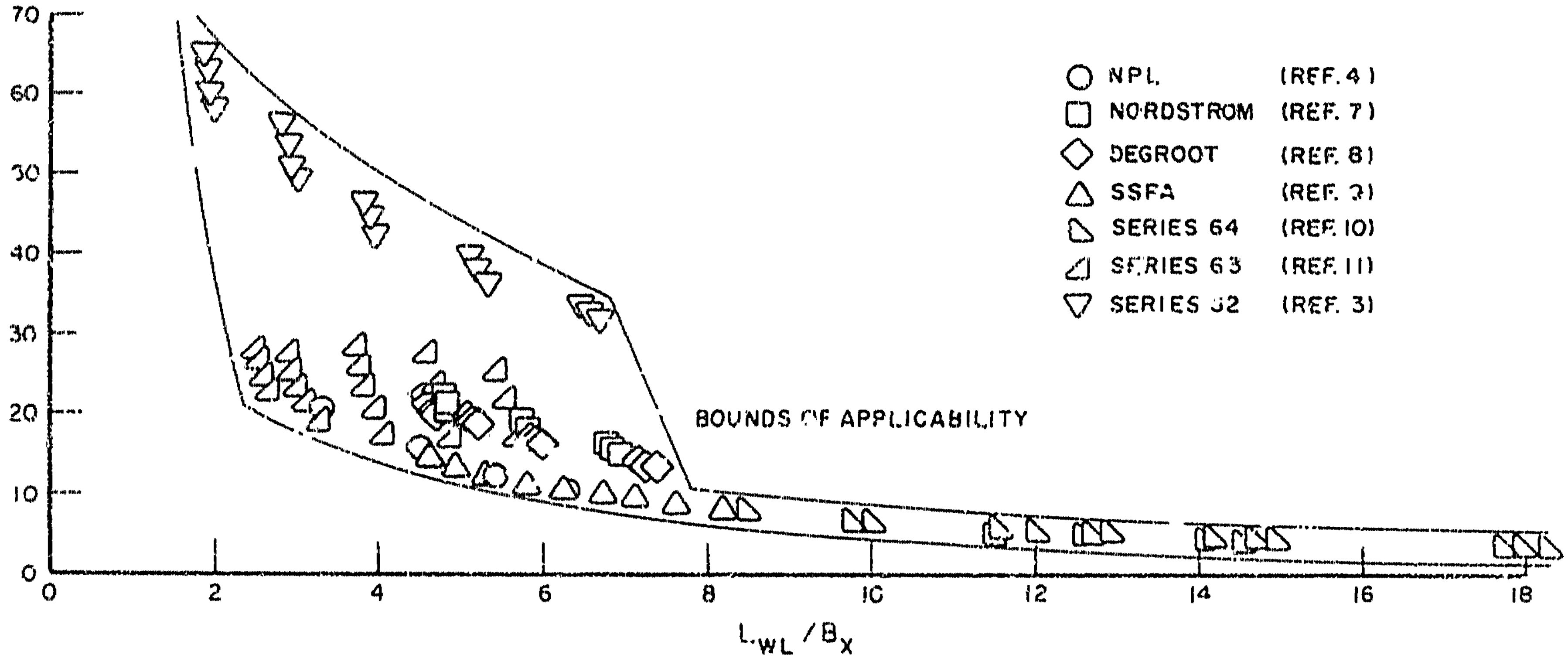

FIG. 15 RANGE OF VARIATION OF i_e AS A FUNCTION OF L_{WL}/B_X FOR MODELS USED IN DEVELOPING RESISTANCE-ESTIMATING EQUATION

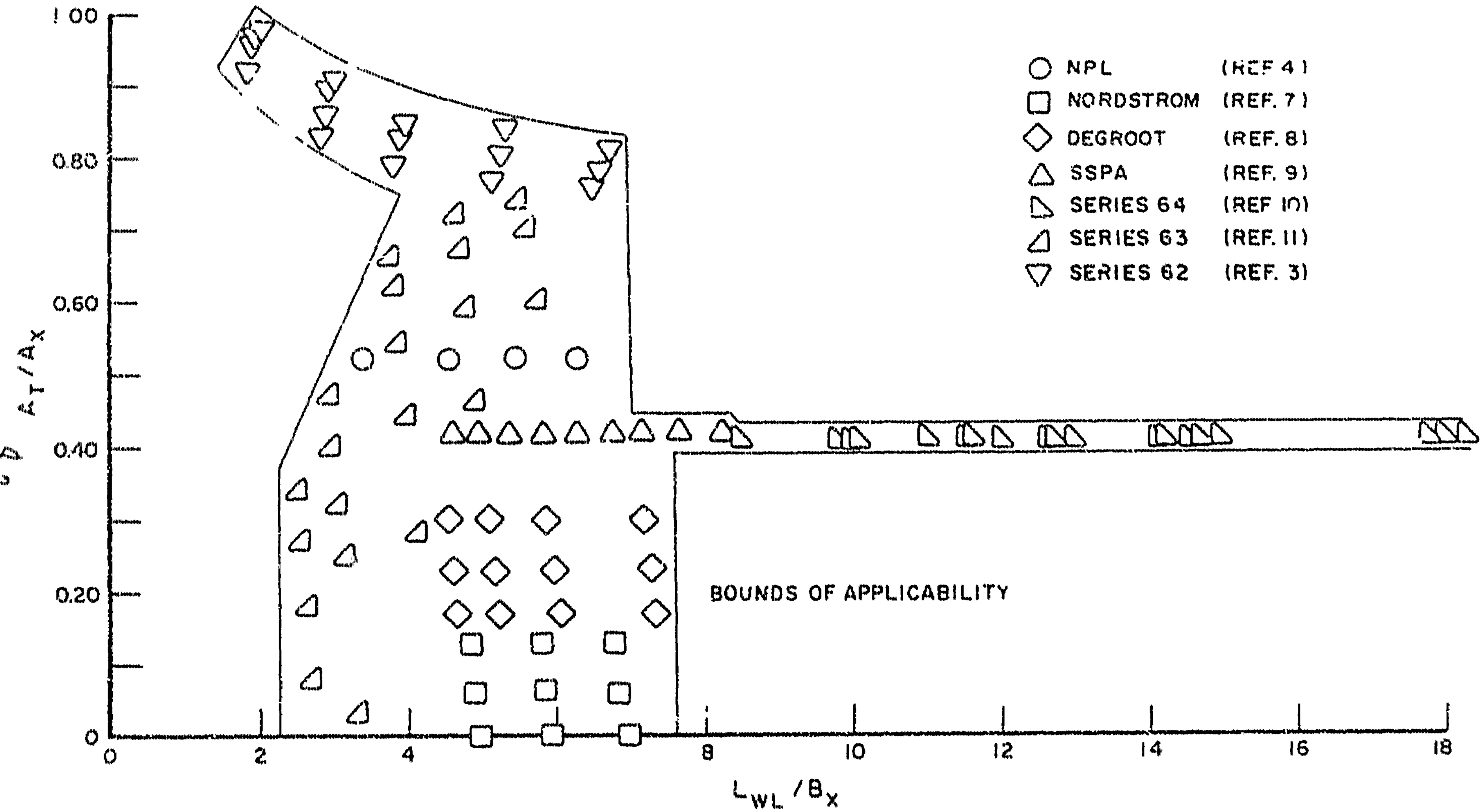

FIG. 16. RANGE OF VARIATION OF A_T/A_X AS A FUNCTION OF L_{WL}/B_X FOR MODELS USED IN DEVELOPING RESISTANCE – ESTIMATING EQUATION

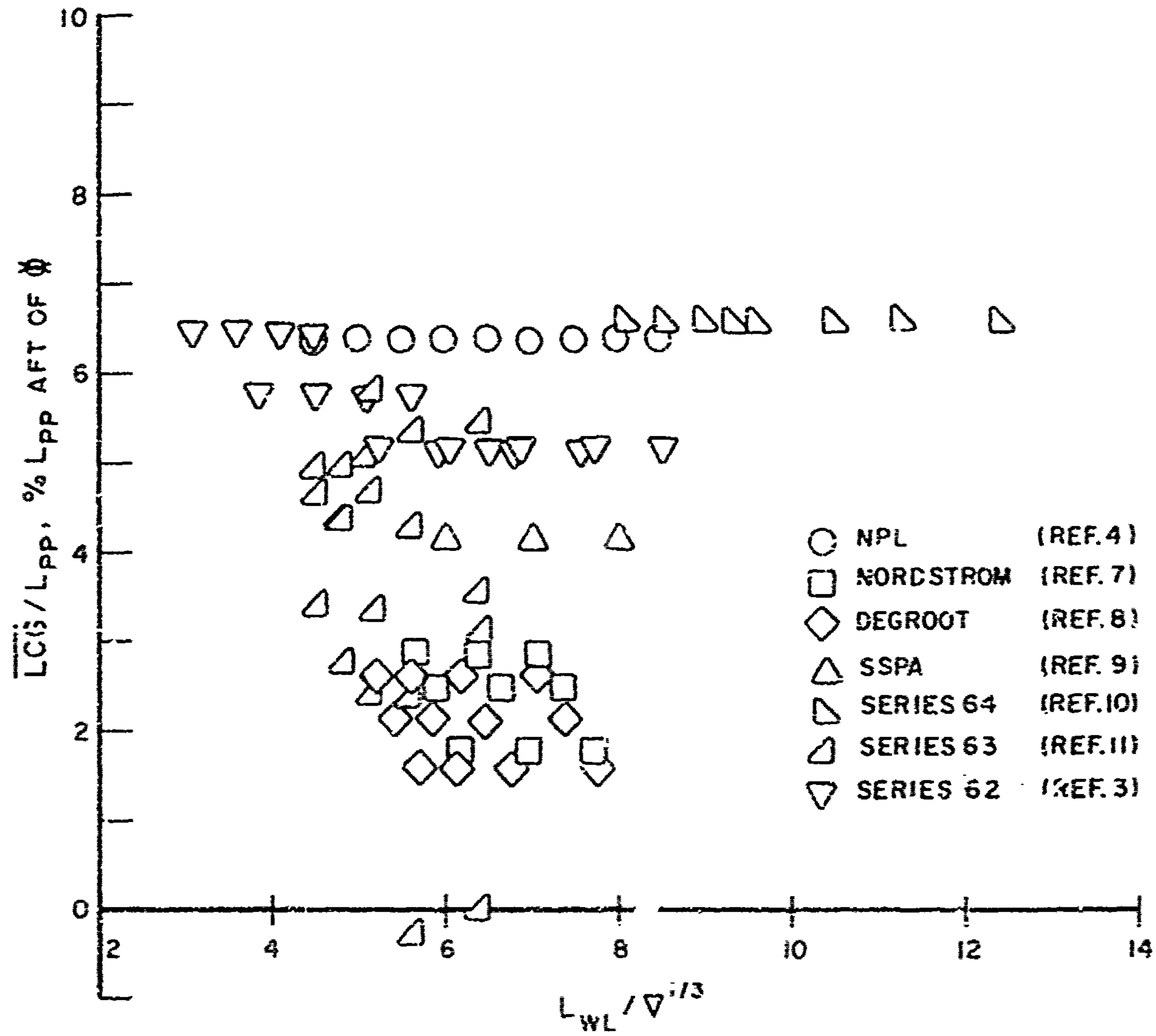

FIG. 17. RANGE OF VARIATION OF $\overline{LCG}/L_{PP}$ AS A FUNCTION OF $L_{WL}/\nabla^{1/3}$ FOR MODELS USED IN DEVELOPING RESISTANCE-ESTIMATING EQUATION

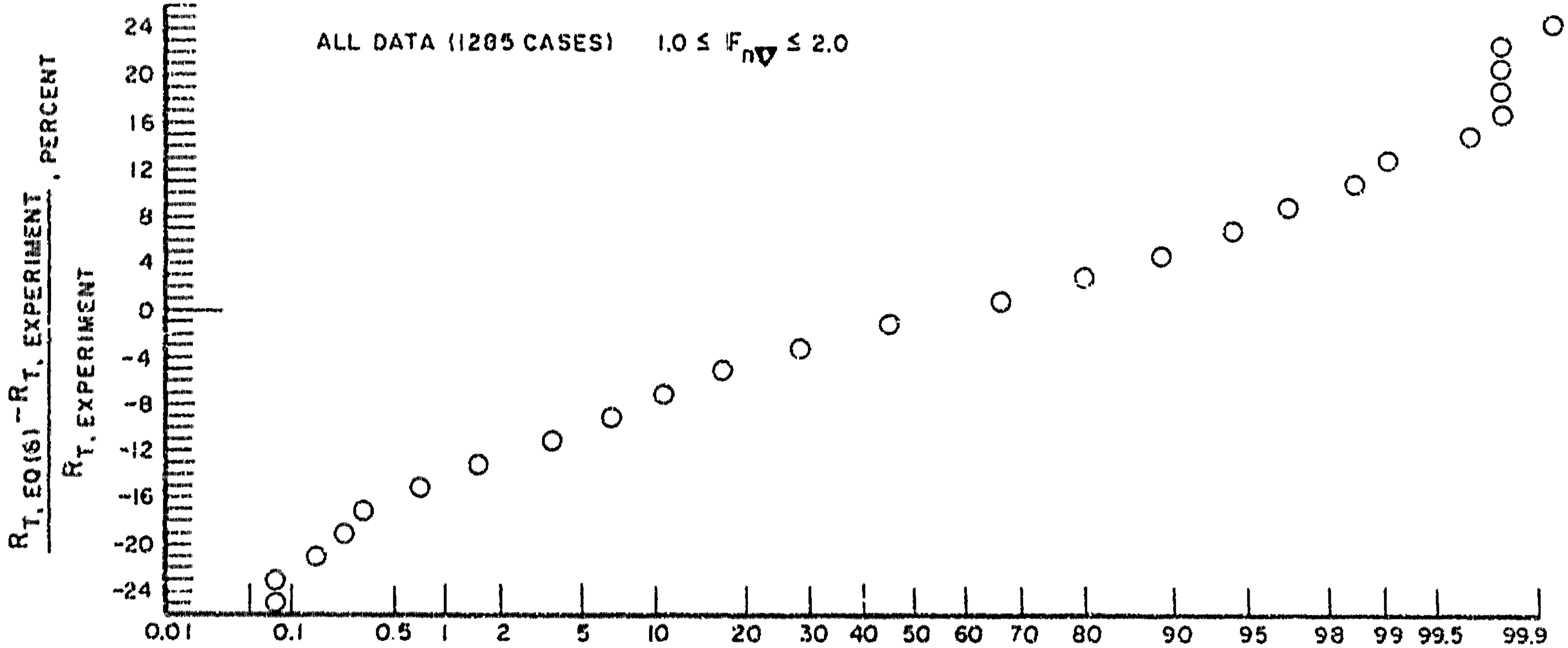

FIG. 18. DISTRIBUTION OF PERCENT ERROR IN RESISTANCE ACCORDING TO DERIVED RESISTANCE-ESTIMATING EQUATIONS

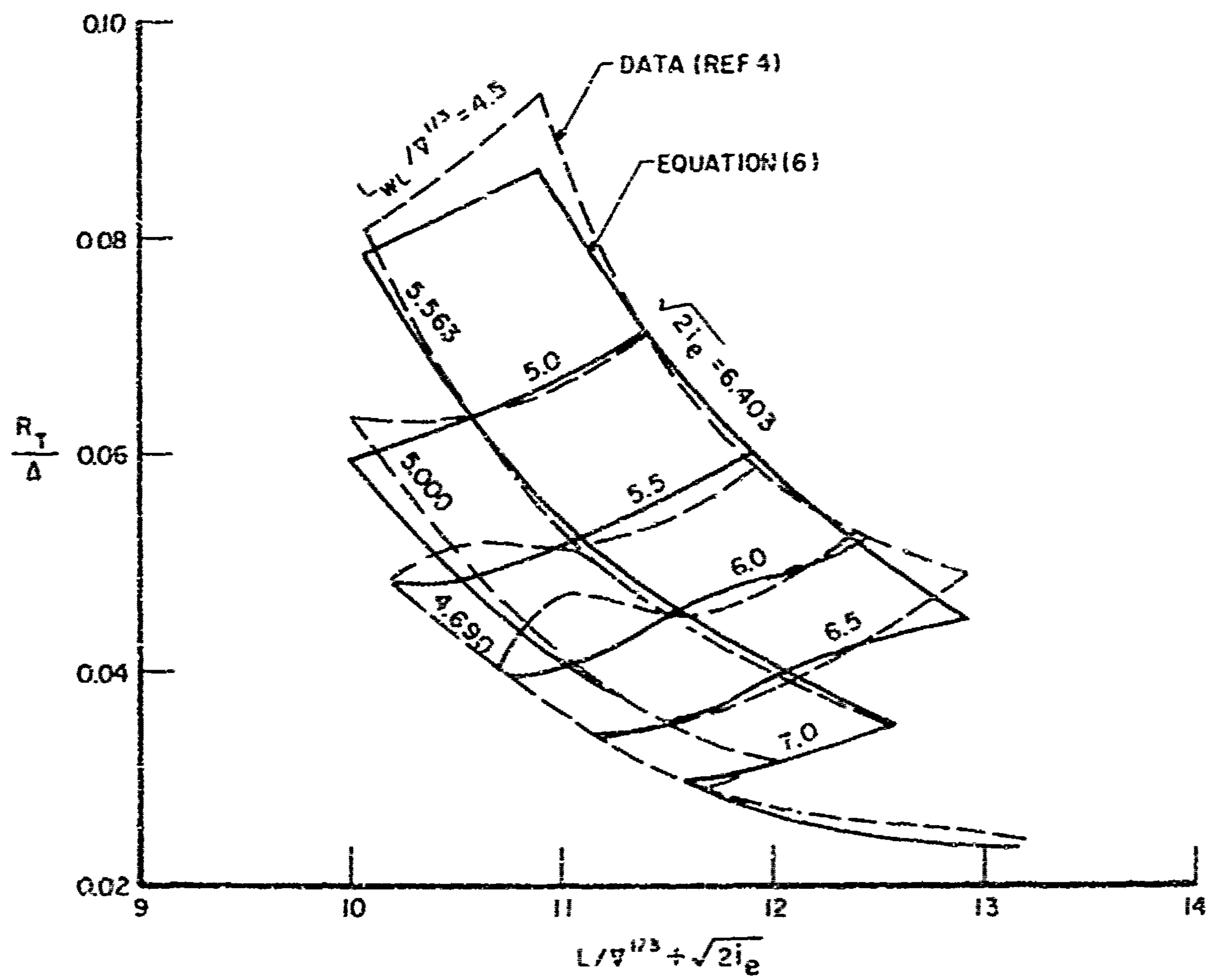

FIG. 19a. COMPARISON OF CALCULATED RESISTANCES WITH MEASURED VALUES FOR MODELS OF NPL SERIES AT $F_{n\nabla}=1.1$

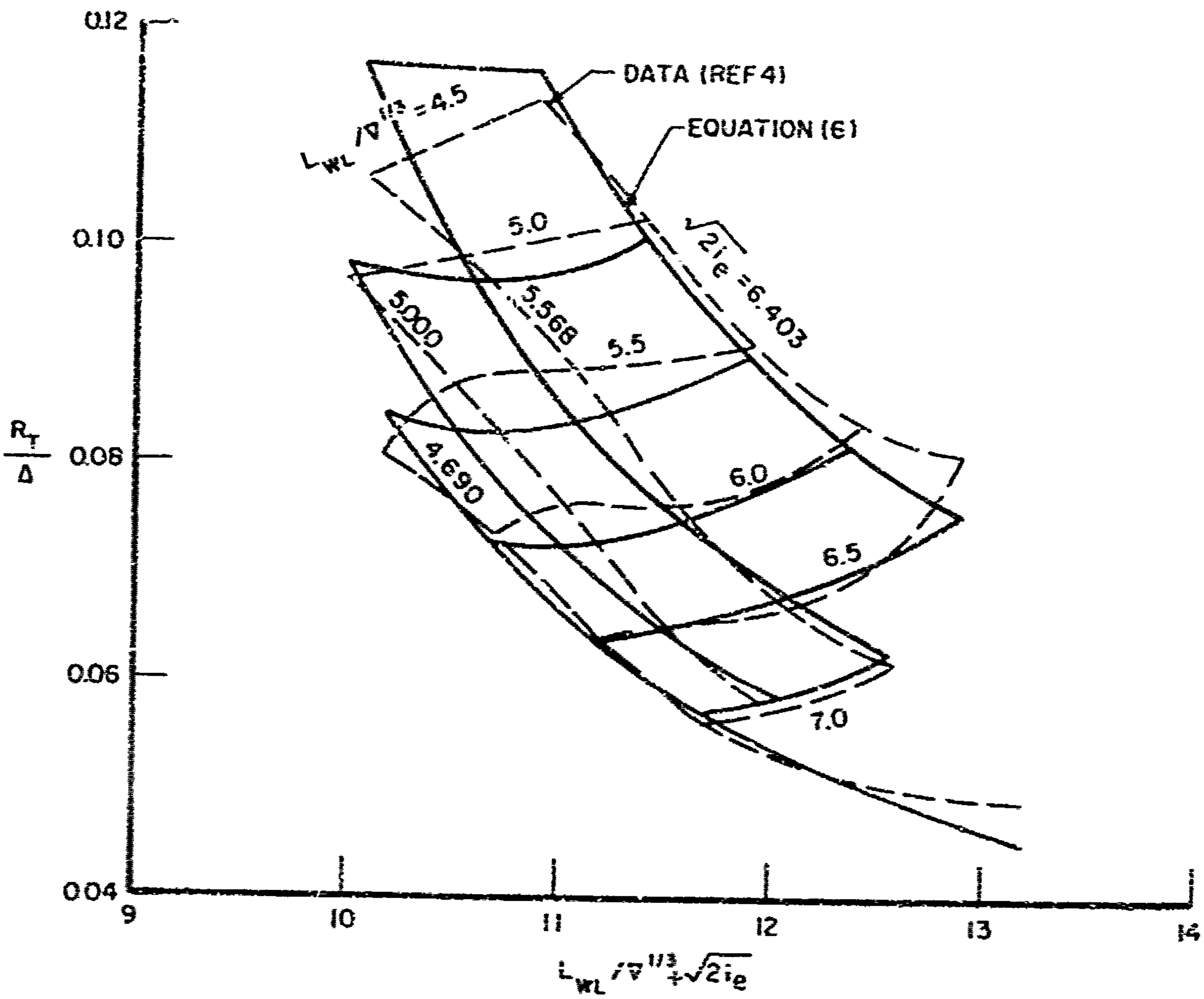

FIG. 19b. COMPARISON OF CALCULATED RESISTANCES WITH MEASURED VALUES FOR MODELS OF NPL SERIES AT $F_{n\nabla} = 1.5$

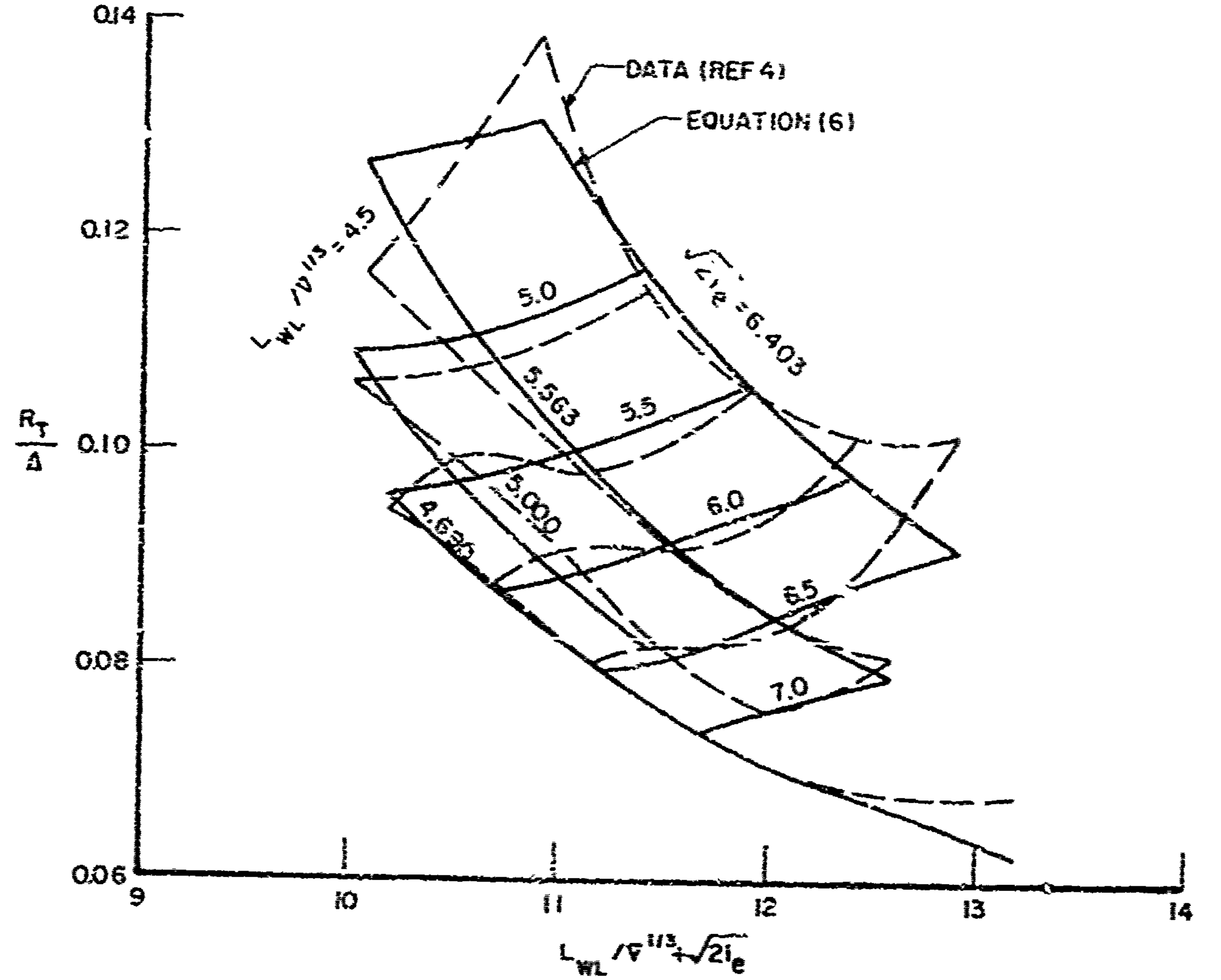

FIG. 19c. COMPARISON OF CALCULATED RESISTANCES WITH MEASURED VALUES FOR MODELS OF NPL SERIES AT $F_{n\nabla}=1.9$

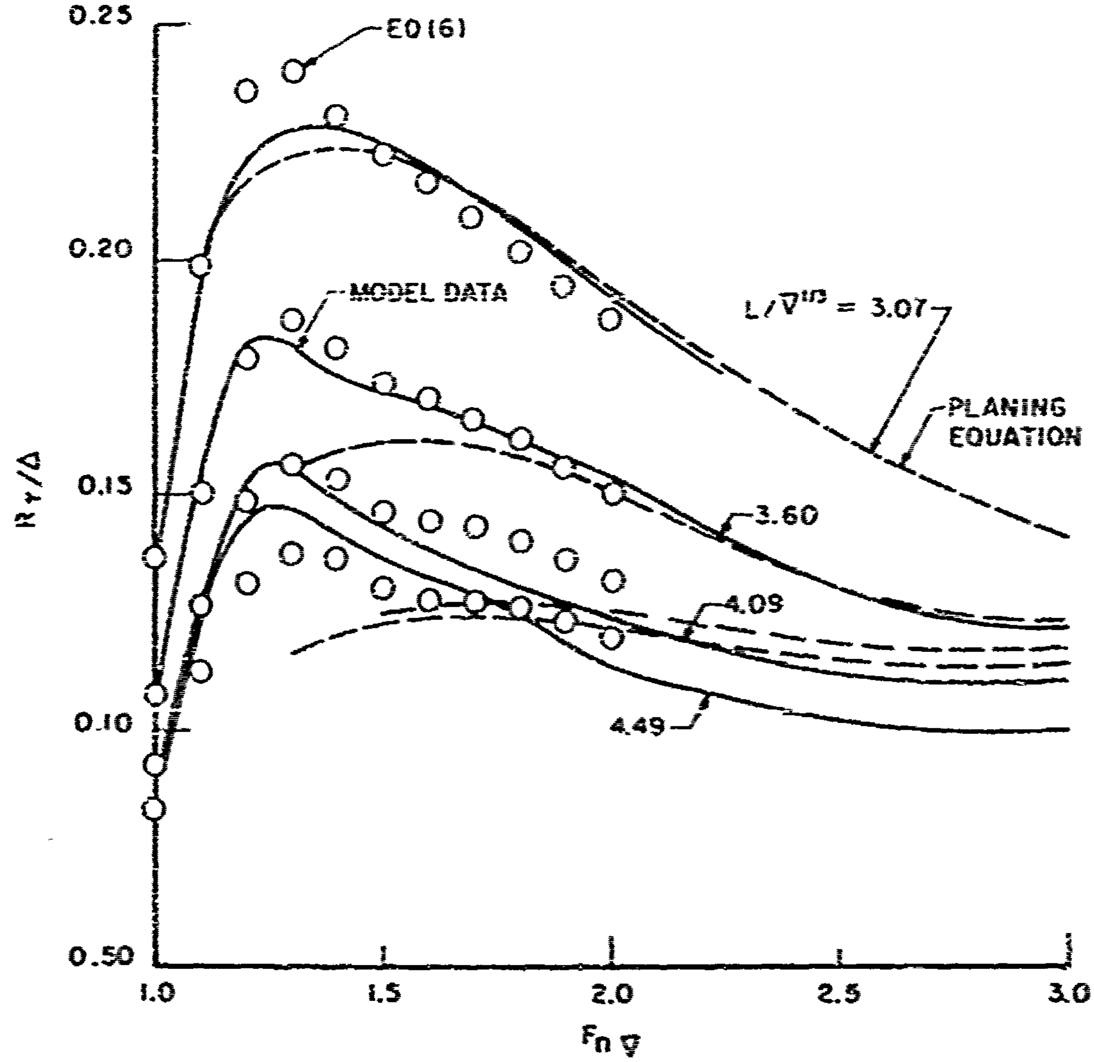

FIG. 20a. COMPARISON OF PREDICTED RESISTANCE ACCORDING TO DERIVED RESISTANCE-ESTIMATING EQUATION AND TO PLANING EQUATION WITH MEASUREMENTS FOR MODEL 4665 OF SERIES 62.

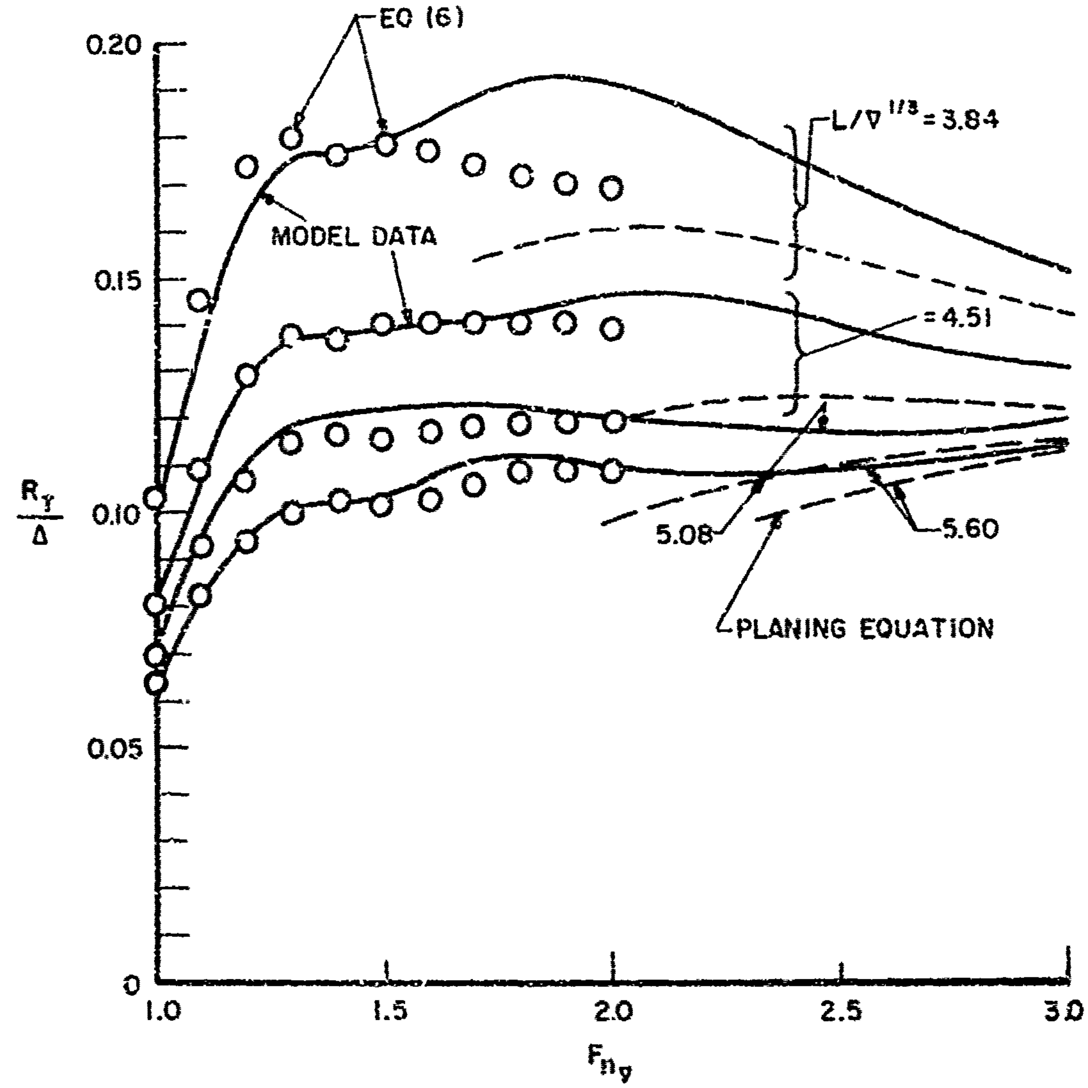

FIG.20b. COMPARISON OF PREDICTED RESISTANCE ACCORDING TO DERIVED RESISTANCE-ESTIMATING EQUATION AND TO PLANING EQUATION WITH MEASUREMENTS FOR MODEL 4666 OF SERIES 62

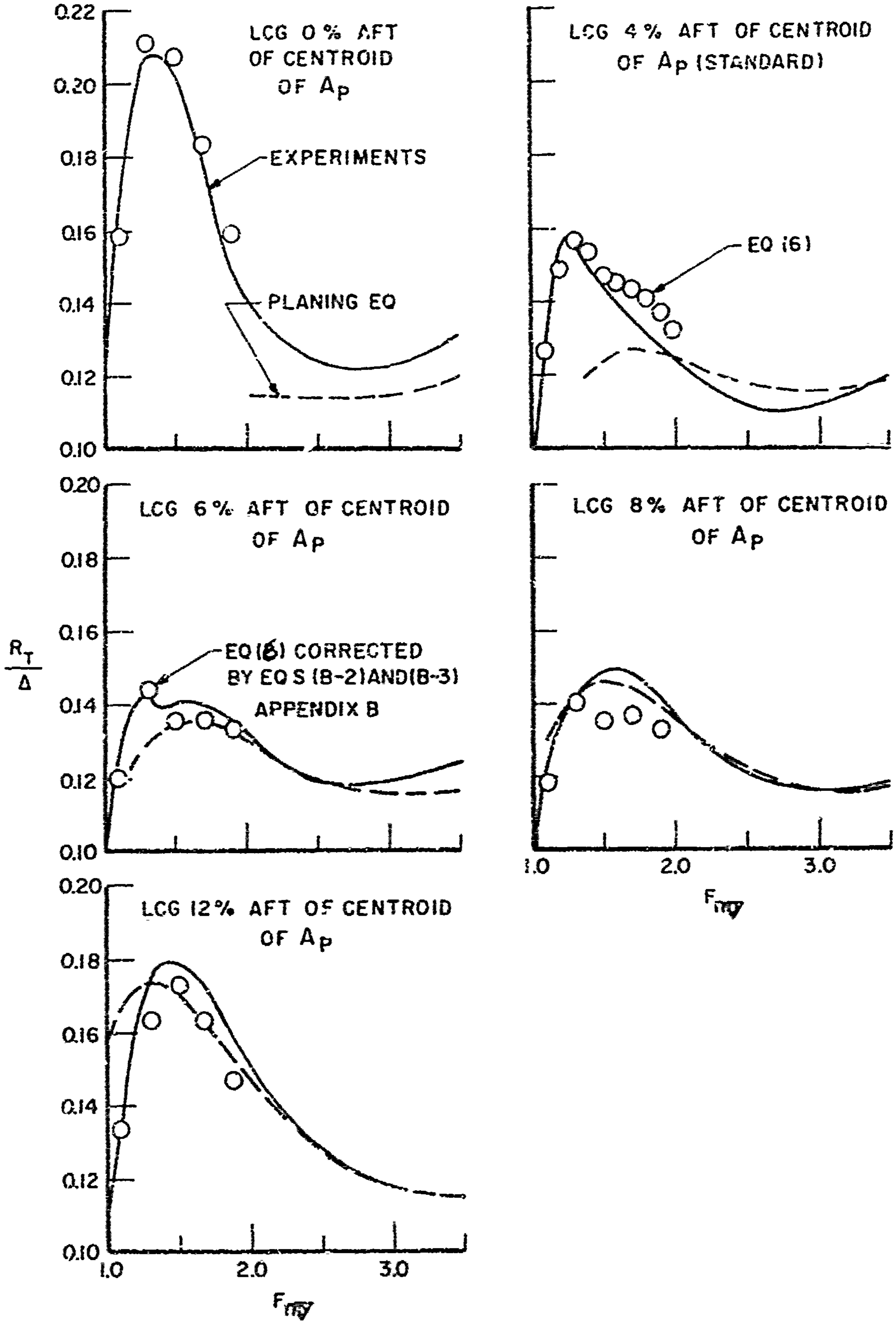

FIG. 21. EFFECT OF VARIATIONS IN LCG POSITION ON RESISTANCE OF SERIES 62 MODEL 4665 AT $L/\nabla^{1/3} = 4.09$ ($A_p/\nabla^{2/3} = 7.0$)

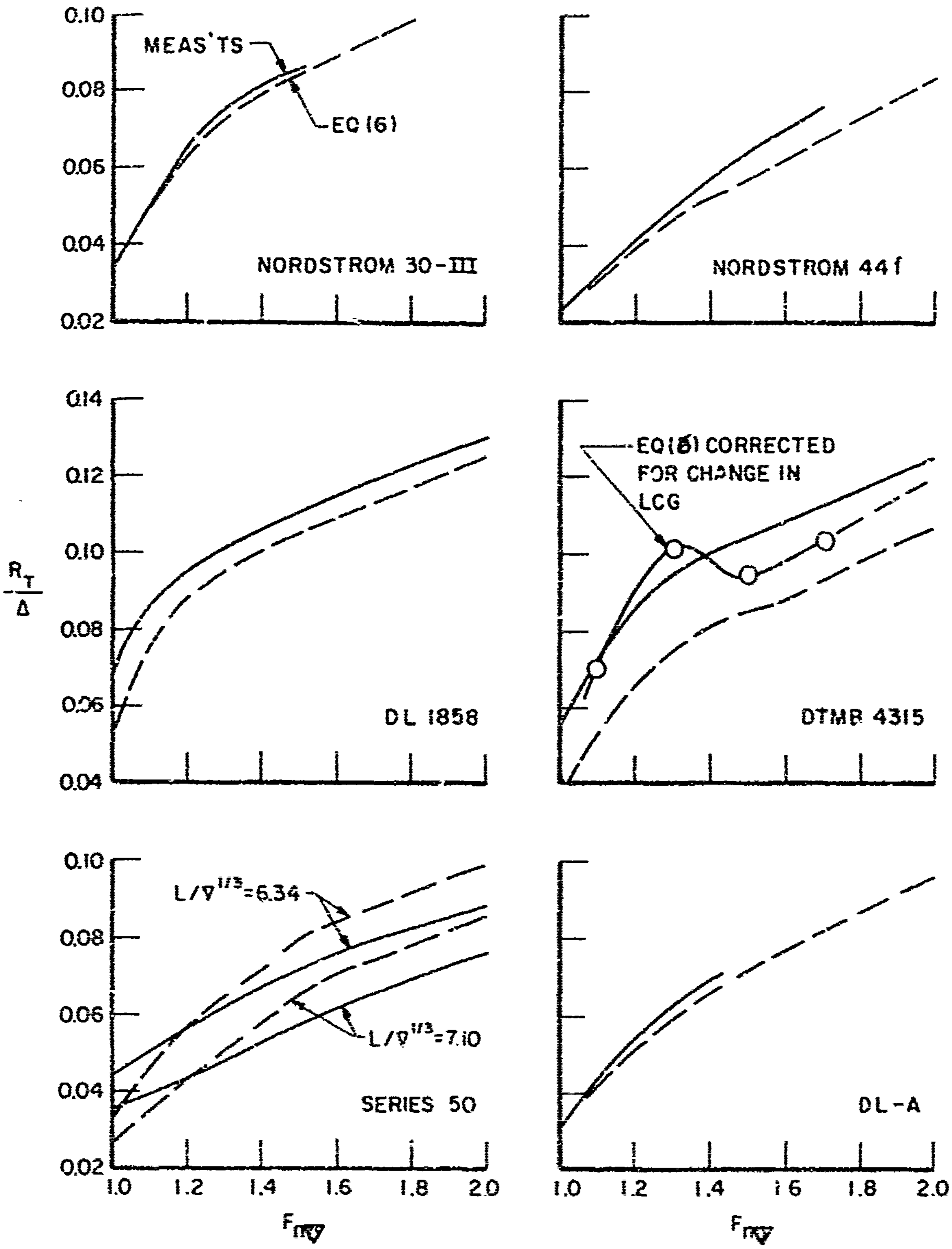

FIG. 22. COMPARISONS OF RESISTANCE ESTIMATES FROM EQ (6) WITH RESULTS OF MEASUREMENTS FOR AD-HOC CASES (TABLE VIII)

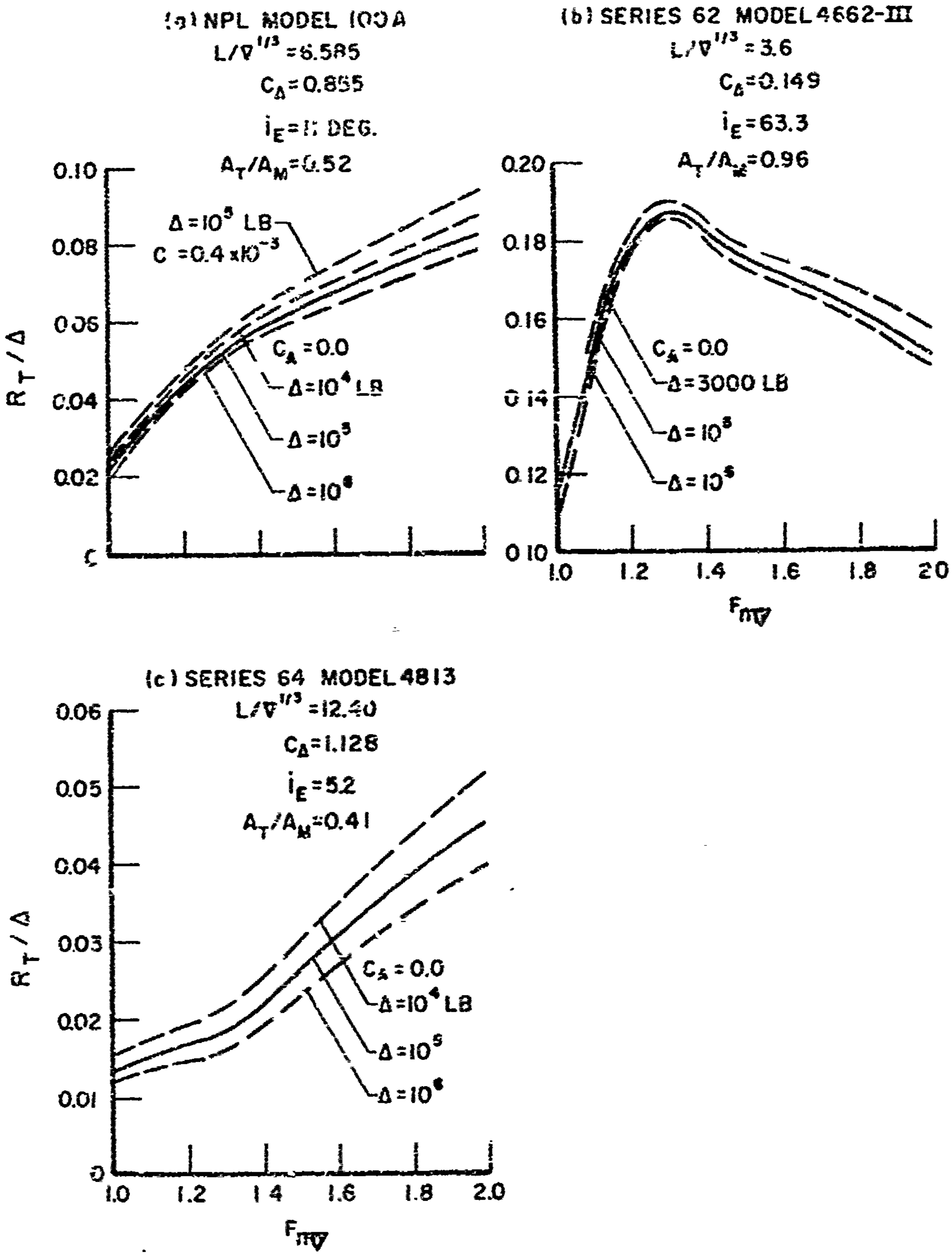

FIG. 23. EFFECT OF VARIATION IN DISPLACEMENT ON ESTIMATED R_T/Δ FOR THREE HULLS HAVING DIFFERENT PROPORTIONS

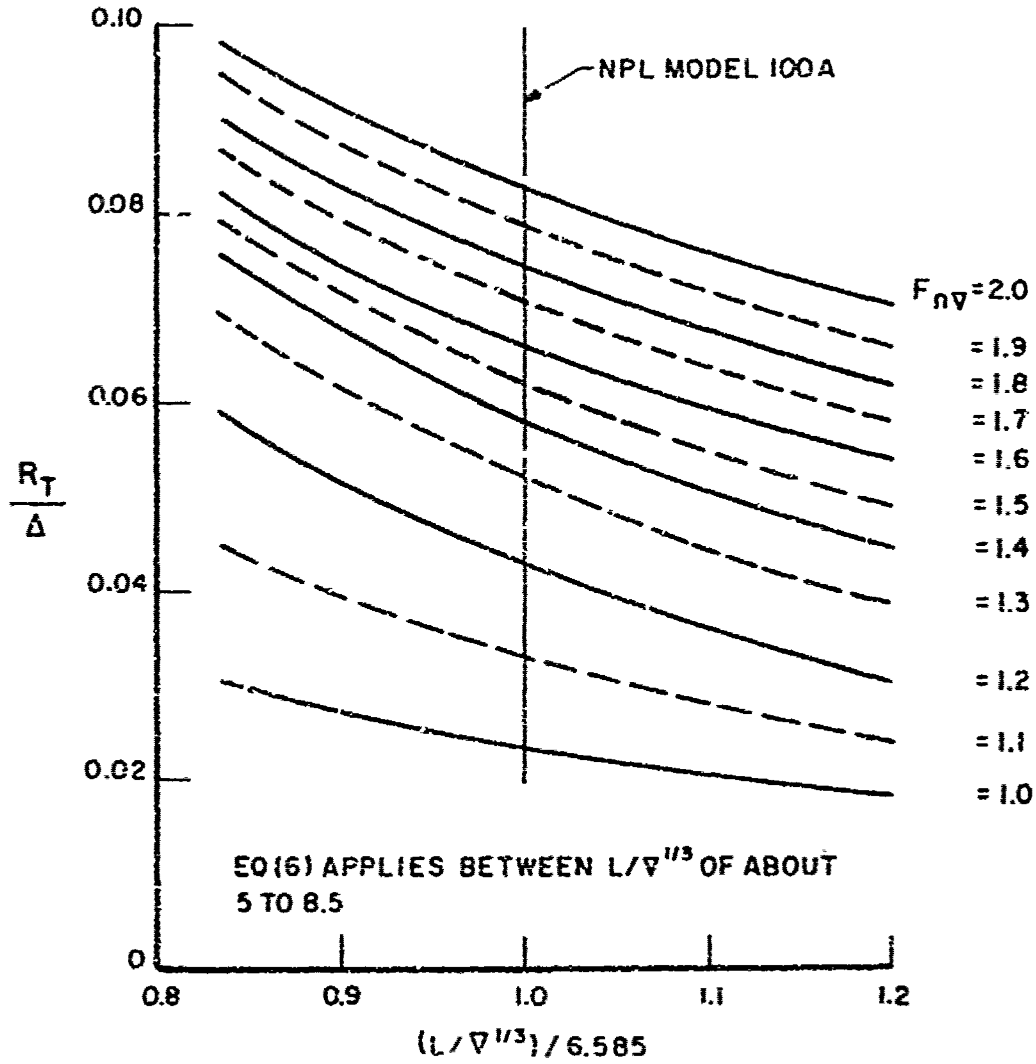

FIG. 24a. INFLUENCE OF VARIATIONS OF $L/\nabla^{1/3}$ ON R_T/Δ, FROM EQ (6) FOR A PARTICULAR HULL FORM

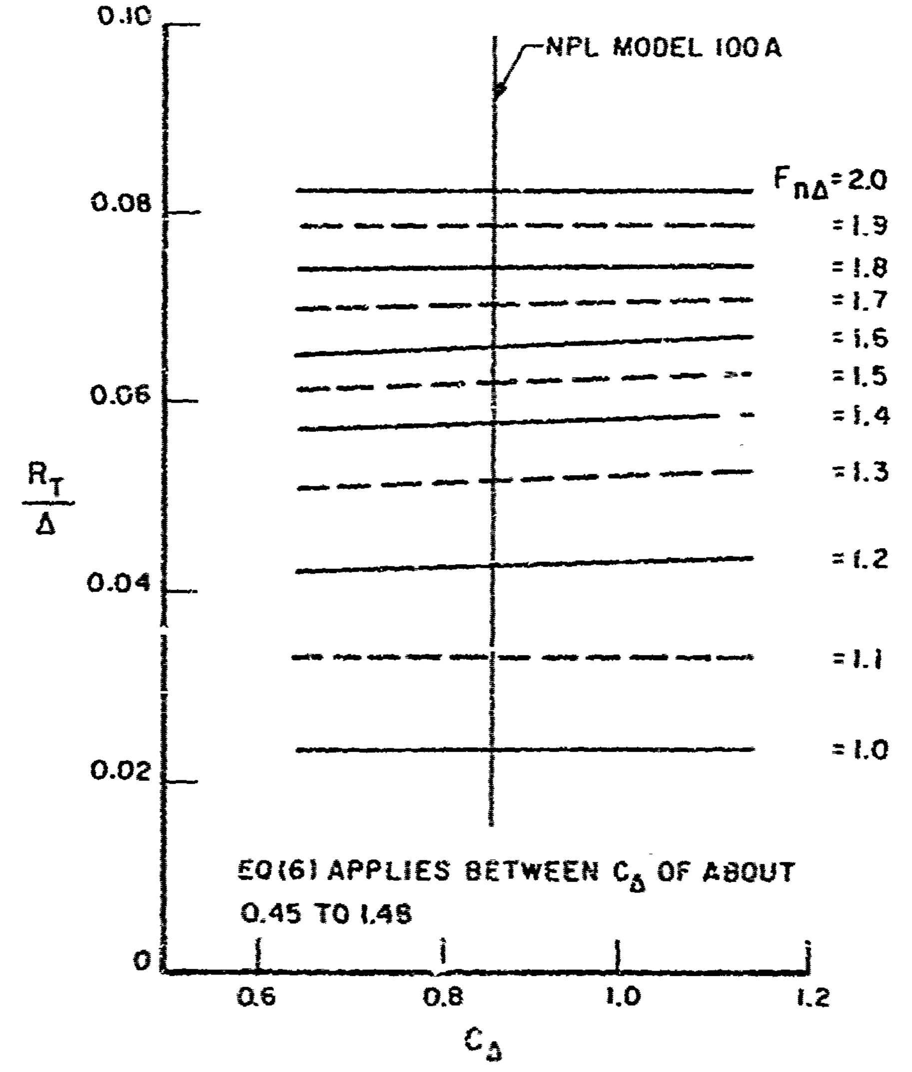

FIG. 24b. INFLUENCE OF VARIATIONS OF C_Δ ON R_T/Δ, FROM EQ (6), FOR A PARTICULAR HULL FORM

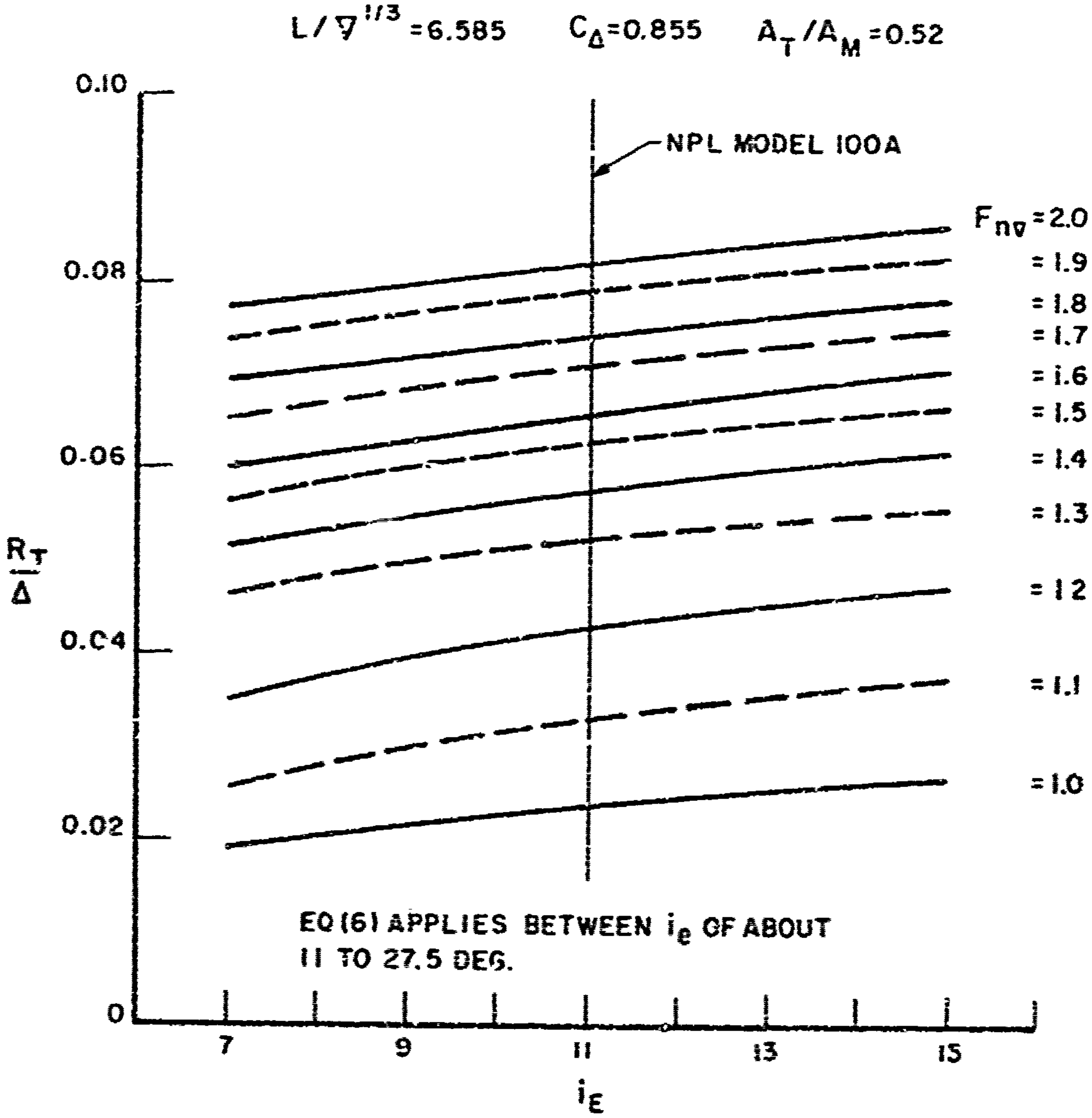

FIG. 24c. INFLUENCE OF VARIATIONS OF i_e ON R_T/Δ FROM EQ (6), FOR A PARTICULAR HULL FORM

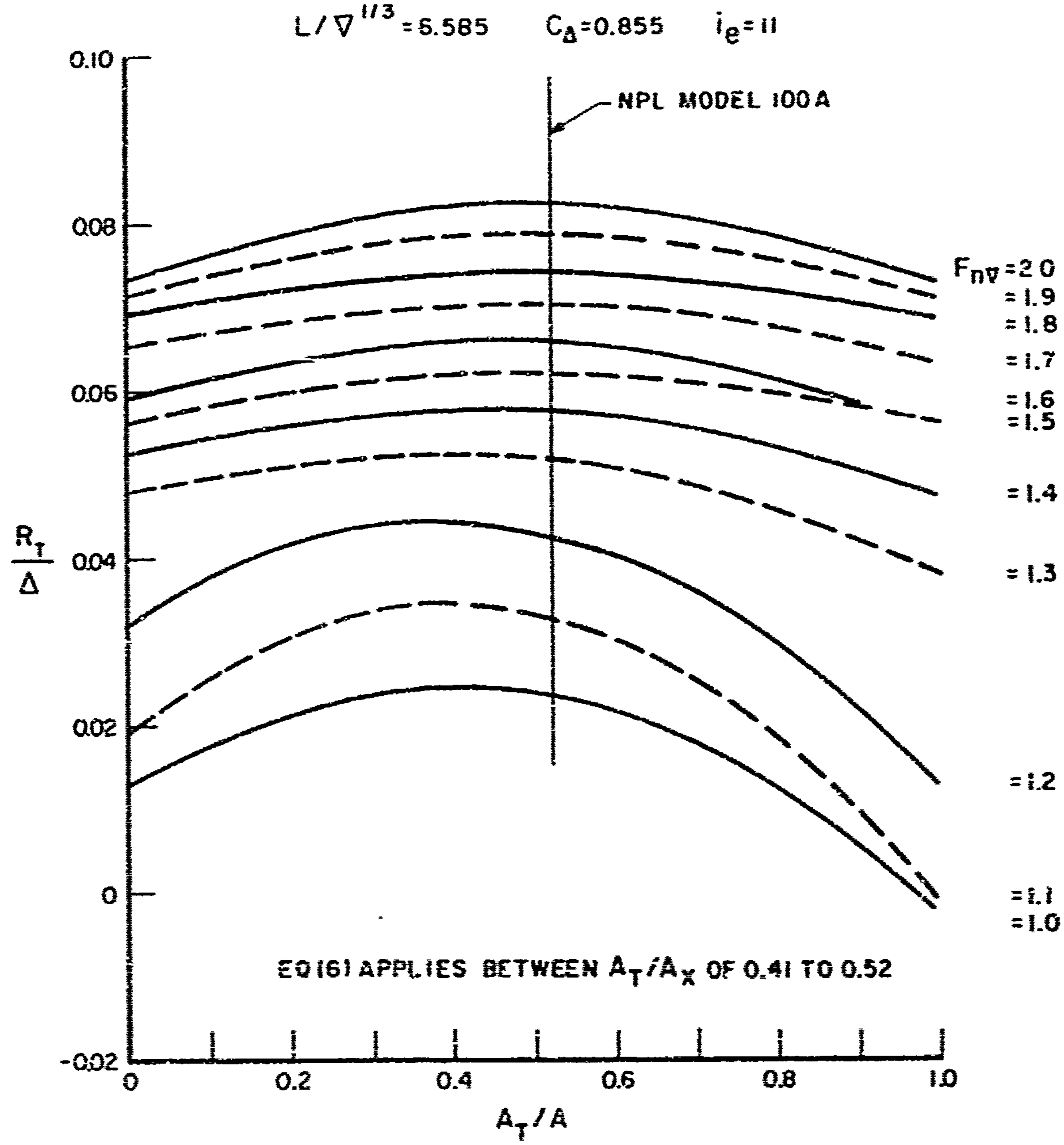

FIG. 24d. INFLUENCE OF VARIATIONS OF A_T/A ON R_T/Δ, FROM EQ. (6), FOR A PARTICULAR HULL FORM